This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

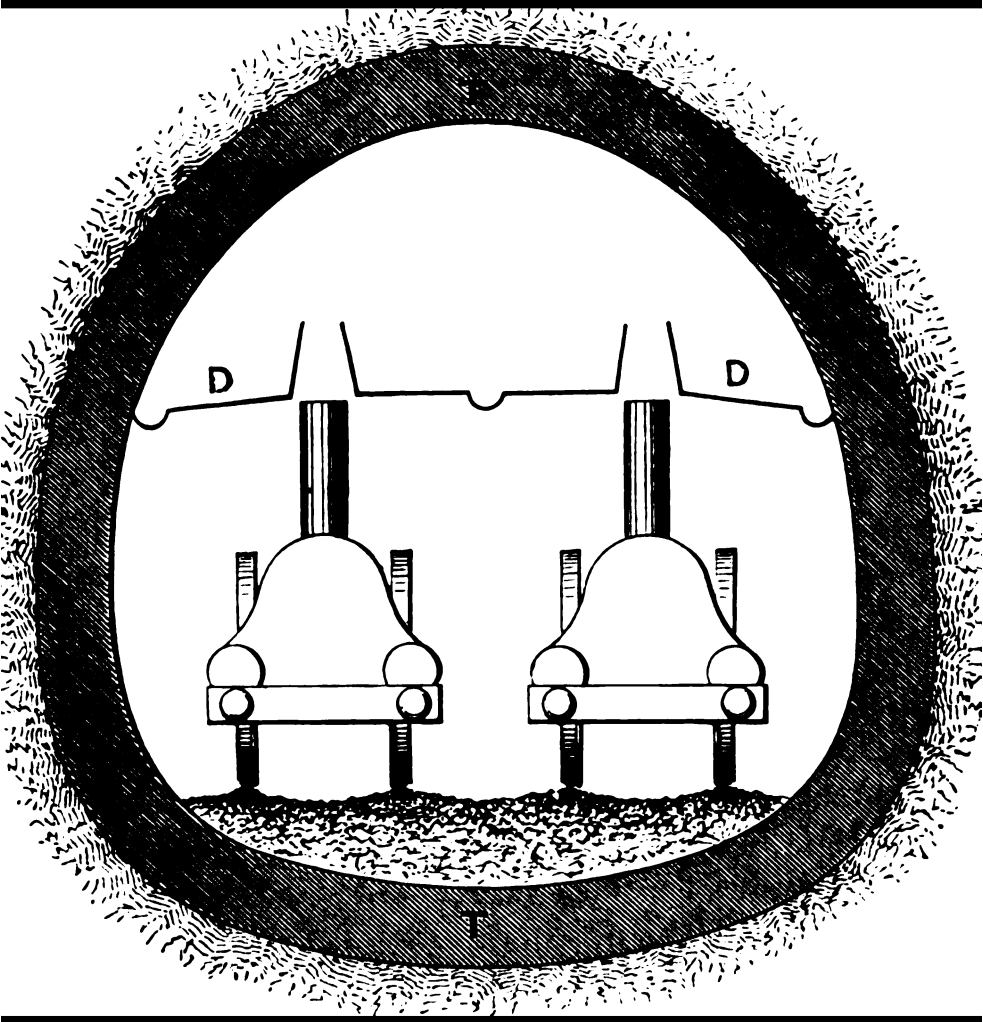
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

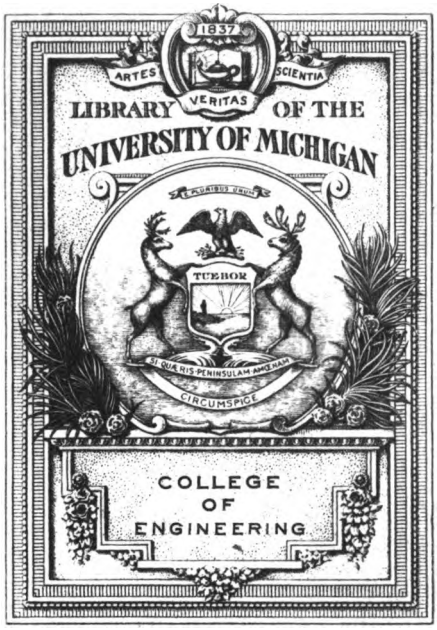
Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`



Minutes of proceedings of the Institution of Civil Engineers

Institution of Civil Engineers (Great Britain)

Digitized by Google



THE GIFT OF
Dean M.E.Cooley

General Library

Digitized by Google

TA
1
.I6m

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. XLIV.

SESSION 1875-6.—PART II.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

INDEX, PAGE 343.

LONDON:
Published by the Institution,
25, GREAT GEORGE STREET, WESTMINSTER, S.W.
1876.

[*The right of Publication and of Translation is reserved.*]

Digitized by Google

ADVERTISEMENT.

The Institution is not, as a body, responsible for the facts and opinions advanced in the following pages.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, STAMFORD STREET AND CHARING CROSS.

Digitized by Google

GIFT
DEAN M. E. COOLEY
9-13-93

CONTENTS.

SECT. I.—MINUTES OF PROCEEDINGS.

January 11, 1876.

PAGE

Election of Associates 1
Transfer of Associates to class of Members 1
Admission of Students 1
Address of Mr. G. R. Stephenson, President 2

January 18 *and* 25, 1876.

"The Ventilation and Working of Railway Tunnels." By G. J. MORRISON. (1 plate) 18
Discussion on ditto (6 woodcuts) 50

February 1, 1876.

Election of Members and Associates 95
Transfer of Associate to class of Member 95
Admission of Students 95
"Holyhead New Harbour." By H. HAYTER. (2 plates, 8 woodcuts) . . 95
Appendix: Tables of Statistics 110
Discussion on ditto (3 woodcuts) 113

February 8, 1876.

"Carlingford Lough and Greenore." By J. BARTON. (3 plates) 131
Discussion on ditto 143

February 15, 1876.

"On Estimating the Illuminating Power of Coal Gas." By W. SUGG . . 151
Discussion on ditto 159

Digitized by Google

February 22, 1876.

PAGE

"On the Probable Errors of Levelling; with Rules for the Treatment of Accumulated Errors." By W. AIRY. (2 woodcuts) 174
Appendix: Details of working out of an example 187
Discussion on ditto 193

SECT II.—OTHER SELECTED PAPERS.

"The Lagoons on the South-East Coast of Ireland." By G. H. KINAHAN. (1 plate) 204
Memoirs of Deceased Members 219
General Constantine Tscheffkine, 219; Thomas Hardinge Going, 221; James Stirling, 221; Augustus Beattie Bradbury, 224; Seymour Clarke, 225; George Cæsar Cooke, 228; Jesse Hildred, 228; Evan Leigh, 229; William Chadwell Mylne, 232; Francis Napier, 232; Philip Algernon Herbert Noyes, 233; James Robertson, 234; Peter Thomson, 235.

SECT. III.—ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Experiments on Cements at Bangalore. E. NICHOLSON 238
Concrete Dam for the Geelong Waterworks. G. GORDON. 241
On Testing the Stability of Iron Bridges. M. ST. VENANT 241
Account of the Rebuilding of the Bridge of Andé on the Seine. R. BONNIN 242
The Foundations of the Saulze Bridge. P. BONHOMME 244
Viaduct over the Valley of the Luech. M. CHABASSU. 246
Narrow-Gauge Mountain Railway, Rostoken to Marksdorf. P. KLUNZINGER 247
Breslau-Schweidnitz-Freiburg Railway. H. WIEBE 248
Slipping of Tiligul Embankment, Odessa-Balta Railway. J. PANDER . . 250
Use of Cast and Wrought Iron for Railway Sleepers. L. KIRSCH . . . 252
The Heberlein Break. M. MASSAUGE 254
Compressed-Air Tramway Car. M. MÉKARSKI. 254
On the Flow of Water in Pipes. P. BOILEAU 257
Researches on the Form of the Longitudinal and Cross Sections of Gravel-Bearing Rivers. H. STERNBERG 258
Floods of the Garonne and other Rivers in France in 1875. M. BELGRAND 261
On the Flood of the Seine in February-March, 1876. M. BELGRAND . . 262
Hydraulic Experiments at Roorkee. Captain A. CUNNINGHAM, R.E. . . 263
On the Closing of an Arm of the Danube. J. PRUCHA 266
New Type of Movable Dam. M. BOULE. 268
Laying a Submarine Water Pipe in Pola Harbour J. PRUCHA 270

Digitized by Google

PAGE

The Improvement and Enlargement of the Port of Genoa. F. Ciocca and V. Chiavacci 271
On the Chemical Composition of the Sewage Liquid and of the Effluent Water of the Dantzic Irrigation Works. O. Helm 276
The Results of Sewage Irrigation at Dantzic. Dr. Lissauer 279
Hydraulic Motors of Switzerland. W. Weissenbach 282
On the Mechanical Properties of Saturated Vapours in Vacuo. C. Antoine 283
On the Value of the Co-efficient of Expansion of Superheated Steam. M. Croullebois 284
Hétet's Method of Purifying the Water from Surface-Condensers. E. Lacroix 284
Steam Brick-Kiln. H. W. Adams 285
Steam Railway Pontoon 286
Deep Sinking for Coal at Peremba in Upper Silesia. H. Schantz . . . 287
Peat as Fuel for Industrial and Domestic Purposes. A. Lencauchez . . 289
On the Use of Pulverised Fuel. B. F. Isherwood 289
On the Study of Thermic Motors, and on certain points of the Theory of Heat. G. A. Hirn 292
M. Hirn's Method of Testing Steam-Engines, and its Application. F. L. Poupardin 293
Résumé of M. Hirn's new Work on the Mechanical Theory of Heat. O. Hallauer 296
Theory of Superfusion and Supersaturation, after the Principles of the Mechanical Theory of Heat. M. de Coppet 298
On the Laws of Gases. D. Mendéléeff 299
On the Co-efficient for Expansion of Air under Atmospheric Pressure. D. Mendéléeff and N. Kaiander 300
On the Specific Heat of Gases. E. Wiedemann 301
The Relative Value of Blows and Pressure. Prof. F. Kick 302
The Insufficiency of the Tests in Use for Steel Axles. R. L. Haswell . . 307
The Utilisation of Heat in Furnaces. L. Gruner 310
On the Temperature of Gas Furnaces. S. Périssé 312
On the Composition of the Gases of the Bessemer Converter. A. Tamm . 313
Effects of Silicon and Manganese on the Properties of Steel. F. Gautier . 316
Regenerative Furnaces for Glass-Works, &c. T. Kleimvachter . . . 318
Analysis of the White Smoke from a Blast Furnace near Longwy. L. Gruner 319
On the Expansion and Specific Heat of Fusible Alloys. W. Spring . . 320
On the Absorption of Gases by Iron and Steel. MM. Troost and Hautefeuille 320
Preservation of Timber. L. Boulart 322
On Lubricating Oils. MM. Farez and Boullanger 323
The Aërophore Rouquayral-Denayrouze. A. Habets. 325
On the Artificial Cooling of Air by Contact with a Cooled Liquid. MM. Mignon and Rouart. 326
Refrigerating Machine. P. Giffard 327

Digitized by Google

PAGE

On the General Theory of Duplex Telegraphy. L. SCHWENDLER . . . 328

Measurement of the Velocity of Transmission of Electricity in Suspended Wires. W. SIEMENS. 332

On the Electric Conductivity of Inferior Conductors. T. DU MONCEL . . 334

Fluid Dielectric Constants. P. SILOW 336

Automatic Hughes' Apparatus 337

Lightning-Conductors. E. SAINT-EDME. 337

Experiments with the Gramme Electro-Magnetic Machine. H. TRESCA . 338

On the Electric Light for Industrial Purposes. H. FONTAINE 339

On the Accuracy of Chain Measurements. J. WASTLER 340

INDEX 343

ERRATUM.

Vol. xliv., page 91, in Table line 2, column headed 2, *for* "0·5" *read* "1·5."

Digitized by Google

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1875-76.—PART II.

Sect. I.—MINUTES OF PROCEEDINGS.

January 11, 1876.

GEORGE ROBERT STEPHENSON, President,
in the Chair.

The following Candidates were balloted for and duly elected:—Frederick Augustus Abel, F.R.S., Richard Ernest Brounger, Stud. Inst. C.E., Edward Alexander Dunn, Stud. Inst. C.E., Martin William Browne Ffolkes, Stud. Inst. C.E., Capt. Albert Henry Hime, R.E., Arthur Mead, John Hemphill Morant, Oscar Reichenbach, Ernest Edward Sawyer, B.A., Stud. Inst. C.E., John Hume Smith, Stud. Inst. C.E., and Francis Vigers, as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. 8, of the Bye-Laws, had transferred Robert Elliott Cooper, James Graham, Arthur Jacob, B.A., William Luke, and Joseph Fox Sharp from the class of Associate to that of Member.

Also that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:—Henry William Bennett, Henry Parsall Burt, George Chatterton, Harry Withers Chubb, Bertram William Cook, Godfrey Darbishire, James Grundy, Walter Home, Edward Innes, Thomas Jacob, Frederick Martin Jones, Herbert Purnell Mayes, Richard Marion Parkinson, Seymour Blanshard Pemberton, William Wilkinson Squire, Lewis Gordon Tyrrell, and Robert Stodart Wyld, Jun.

Digitized by Google

Mr. STEPHENSON addressed the Meeting in the following terms, on taking the chair for the first time, after his election as President:—

GENTLEMEN,

My first duty is to thank you for the high honour that you have conferred on me by electing me to be your President. At the same time I very earnestly ask you to continue the valuable aid which has for so many years maintained the prestige of this Institution, and will, I hope, enable me to carry on the work with the success which has distinguished the Presidency of my able friend and predecessor, Mr. Harrison. I am fully sensible of the responsibilities belonging to a position of which any member of our great profession might well be proud. In accepting the onerous duties that are inseparable from it I look to you,—I will not say for indulgence in any shortcomings of my own,—but for that ready co-operation, which my predecessors have never asked for in vain, and without which I cannot hope to fulfil the claims of the office.

I am sure you all share with me a feeling of deep regret, that the continued indisposition of your late senior Vice-President, Mr. Hemans, has prevented him from taking the place which I now occupy. We all know how well he was entitled to it by many years of faithful service in your councils, and by those personal and professional qualifications which rendered him so worthy a representative of this Institution.

It has been customary for your Presidents, in their addresses, not only to pass before you, as it were, in a general review, the engineering works of the period immediately preceding their accession to office, but to recall, often in a picturesque, and always in an interesting manner, the earlier and more remote achievements of the founders of our profession. I can propose no such task to myself, not only because those who have been before me have already carefully traced the history of various branches of engineering science, but because I cannot expect to make any useful addition to the series of interesting sketches which have been presented to you from this chair. I shall therefore confine my remarks to a very slight reference to some important works, and to a consideration of subjects which, in my opinion, demand earnest thought and study on the part of engineers, and require intelligent appreciation by the public.

Digitized by Google

Separation of Goods and Mineral Trains from Passenger Traffic on Railways.

Your late President stated, in his address, that,

"Although in England the employment arising from the construction of railways is not so great as it has been, there is still a large amount of work to be done, to meet the increased requirements of the traffic of the country; and in foreign countries this branch of practice will for a long time demand the attention of the rising generation of civil engineers."[1] This is doubtless a correct statement in general terms, and for some time past we have been reminded that extensive railway works in this country are drawing to a close and will necessarily be fewer and fewer. I am strongly of opinion, however, that,—though the works which have yet to be completed, will not afford employment for all who may make railway engineering their special study,—the time is not far distant when very considerable extensions of existing works will be required, to provide for the increased mineral and coal traffic of the country. I refer to the necessity—which is more and more pressing—for increasing the means of transit for heavy "goods trains," and for separating them (and especially the "coal trains") from the pasenger traffic on our crowded main lines. Up to the present time various plans for effecting these objects have been brought before the public. Since the latest of these schemes was proposed there has been an enormous increase of traffic on railways in connection with coal and mineral districts. A great accumulation both of passenger and "goods" service finds the provision of our lines still seriously inadequate, though railway companies have endeavoured to meet the growing difficulty either by forming some new lines or by widening those already at work. Not only public convenience, but public safety demands a very much greater extension still, and I believe that the best, and the most probable remedy, for a condition that may soon become insupportable, is the separation of goods and minerals from the passenger traffic on our main lines. That means must be adopted to simplify the present system is inevitable, and I cannot doubt that those companies whose traffic with the mineral districts is largest, will find it to their advantage to push on the duplication of their lines, in order to meet the exigencies caused by the enormous development of their business, and to effect the division that must soon be imperatively required. The separation, judiciously carried out, will, I think, be an economical advantage.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxvii., p. 227.

Digitized by Google

The greater portion of the stock is already in existence; the cost of management would be little increased, and the gathering lines in the coal fields, the coal depôts, and the lines in London for distribution to the consumers, are already in the hands of the companies. A still greater consideration is, that heavy freights would be conducted at less than half the speed at which they are now conveyed; so that engines would take a largely increased load, and the frequent "shunting," which is so destructive to wagons and causes such loss of time on the road, would be reduced to a minimum. The ordinary wear and tear of running stock would be considerably diminished, while coal would arrive in London in better condition, and would eventually be delivered to the public at a lower price in accordance with decreased cost of transit.

As each year passes new works add their traffic to the already crowded lines, and every year increases the difficulty of carrying on this traffic between frequent passenger trains. At the same time the reduction of the cost of transit by sea is greatly enlarging facilities for carriage by ships.

The erection of extensive docks in the coal rivers, the provision of effective staithes and cranes for rapidly loading and unloading, and better means of communication with the collieries, are advantages which have accompanied the building of a class of larger carrying vessels. To these may yet be added ships of a still larger size, the propelling cost of which will be further reduced, so that there is an absolute certainty of the freights by sea being diminished.

On the other hand, as the increased mineral and passenger traffic on railways are not separated, the existing difficulty of running fast coal trains between passenger trains will continue to add to the cost and danger of transit. Thus, while the cost of the sea route is being reduced, carriage by railway is becoming dearer and dearer. The consequence will be that the shipping trade will command the bulk of the Newcastle and Durham coal freights to London, and when we remember that coal and mineral lines have usually filled the pockets of shareholders to a greater degree than passenger lines, it becomes a matter of great importance to the railway interest that this carrying trade should be secured to it. I think, then, it is obvious that in any case a very large amount of work remains to be done in the shape of additions to the present means of conveyance on railways,—and if the views which I have expressed be correct, a great increase of construction in the shape of new or duplicate lines, together with the public demand for improvements of rivers, drainage of towns, new docks, harbours,

Digitized by Google

land reclamation, and gas and water supply will afford much future employment for engineers in this country.

Harbours of Refuge.

During a recent visit to several places on the Mediterranean was equally surprised and interested by the extent and variety of the great works which, during the last few years, have been constructed for the protection and secure accommodation of shipping, along the whole extent of coast from Marseilles to Naples.

The attention of the English traveller is arrested—even if his national pride be not disconcerted—both by the provision of excellent harbours of refuge, and by the admirable and complete methods which have been adopted for lighting the entire coast.

The magnificent works at Marseilles; the fine harbour at Genoa; the formation of the Bay of Spezzia into a harbour of refuge by means of a breakwater; the grandly conceived half-moon breakwater at Leghorn, and the extensive constructions in progress at Naples, compel the admiration of the English visitor, and cause him to reflect how few and inadequate are the provisions made in his own country for the safety of ships and the protection of life and property at sea.

On parts of our coast, which may be said to be crowded with shipping, the need for maritime works and places of security is painfully obvious, and I was gratified to find on my return from abroad last year, that Sir John Coode had, in an able lecture delivered at the Royal United Service Institution, taken up the subject of providing harbours of refuge, along with those strategic harbours which came more immediately within the scope of his address.

As long ago as 1845 or 1846 it was proposed to construct a harbour of refuge near Margate, and it became my duty to accompany Mr. Rendel and Mr. Robert Stephenson to make an examination of the coast. Shortly afterwards an inspection of the east coast was made with a similar object; but though even at that time the traffic was so great as to arouse serious apprehensions, because of the want of maritime works, for securing the safety of the vessels engaged on that coast, the whole subject was permitted to lapse, and, so far as the east coast is concerned, to fall into oblivion.

It is only those who are actually acquainted with the perils that threaten shipping on the British coast, and who have some practical knowledge of the need for greater security, as well

Digitized by Google

as the means by which it may be attained, that can bring the subject of providing harbours of refuge prominently before the Government and the general public.

Several years ago, in the course of my duties as one of the Engineers-in-chief to the Danish railways, and to canal and reclamation works in Holland, I had frequently to cross the North Sea in all its varied and usually boisterous conditions. I have always been proof against the common enemy of most landsmen, so that I had many opportunities of estimating the extreme difficulties, and of observing the constant dangers, which beset brave and trustworthy men, held responsible for the lives and property of those committed to their charge.

Need I say that the necessity for providing harbours of refuge has vastly increased since that time, and, according to the best information obtainable, continues to increase, because the traffic conducted by the mercantile marine will always be in proportion to the growing commercial activity of the country. Of this commercial activity, the eastern coasts of England represent a very considerable portion; and when we remember that the proportion of wrecks and casualties at sea is also increasing to a terrible extent, it should surely be our duty, on every proper occasion, earnestly to demand that the remedy should be provided efficiently and at once.

From the North Foreland to the Frith of Forth, the east coast has no harbour in which a ship can seek shelter, with anything like safety, in heavy gales.

It is true that at several of the large coal ports a great deal has been done by private enterprise. I may instance those improvements in the Tyne, where a very large expenditure has been incurred in building piers, conducting dredging operations, &c. By these means a much greater depth of water has been obtained; but such works cannot be classed with proper harbours of refuge. They have not even diminished the anxiety or the actual dread which the sailor feels when he is compelled to run for a harbour where the danger to which he is exposed becomes greater after his ship is inside the pier heads.

This painful need of maritime works on our coast is the more remarkable when we observe what has really been effected in those places where some of our foremost engineers have had the opportunities of carrying out their designs.

The magnificent harbour at Holyhead, begun by the late Mr. Rendel and completed under the able management of Sir John Hawkshaw, is regarded by the whole nation, if not by every trading nation in the world, as an inestimable boon to the per-

Digitized by Google

petually increasing fleet of merchant vessels which come from all countries to Liverpool.

The Plymouth breakwater and the Portland breakwater, the latter begun by Mr. Rendel and completed by Sir John Coode, have fulfilled the most sanguine expectations, and are achievements of which the country and the profession are justly proud. The skill with which they were projected, the ability with which they were carried out, and the grand result attained by the saving of life and the preservation of property, have raised them to the rank of some of our greatest national possessions.

From whatever point of view we regard the neglect of the Government to provide harbours of refuge on the east coast, our wonder increases.

Large sums are spent (and doubtless they are well spent) in maintaining training ships, and in instructing lads for becoming sailors in the Royal Navy. At the same time, it is proverbial that "the coasting trade breeds sailors for the service of the country." It surely follows, then, that if it be desirable to spend money in educating a youth to be a sailor, it is no more than the plainest economy to protect and encourage the sailors who are ready-made, and are not only maintained without cost, but contribute, by the enterprises in which they are engaged, to the material prosperity and commercial success of the country.

I cannot quit this topic without expressing my belief, or at any rate my hope, that the time must shortly arrive when there will be a demand that some portion of the heavy revenue derived by the Government from the east coast maritime trade shall be devoted to the purpose of extending to shipping navigating the North Sea, the security of places of refuge such as will give it advantages already enjoyed at other parts of the English coast.

Ocean Steam Navigation.

For several years past, the attention of engineers has been earnestly directed to the great question of improvements in ocean steam navigation; but the general public has very little notion of the difficulties which marine engineers have had to contend with in their endeavours to produce engines capable of affording a maximum speed with a minimum consumption of fuel.

It is remarkable, however, that recent improvements have mostly been founded on an invention which, though admitted to be correct in principle, and admirable as the design of a highly scientific mind, required many subsequent adaptations to secure

Digitized by Google

the success which it has since achieved. The engines which were in use at a period within the memory of some who are here present were incapable of accomplishing distant voyages without visiting numerous stations for the purpose of coaling, a necessity which caused a great increase in the cost of ocean traffic.

Thirty-six years ago Mr. Hall designed, patented, and constructed a marine engine of a new type, which, though it failed at the time to accomplish all that he hoped from it, was destined to overcome the serious difficulties that then beset steam navigation, because of the able experiments and additions which it suggested, and which were afterwards applied to his invention.

Indeed, it is not too much to say that marine engines, even of the most recent construction, are identical in principle with those projected by Mr. Hall, as regards the means adopted for the economy of fuel. This is a very significant fact, worthy of grave attention on the part of some of the younger members of the profession, since it shows the extreme importance of that close attention to practical details without which even the most admirable contrivances may for a long time fail to produce beneficial results. Unhappily, the man who, by his own great ability, presented to the world a plan which, when it was fully understood and wrought out, saved hundreds of thousands of pounds every year, not only died without recompense, but without that recognition of his talents which he had so worthily earned.

Following up his system, however, our marine engineers have succeeded in producing machinery which enables us not only to uphold our position as carriers for the world, but to traverse ocean routes which were formerly beyond the reach of steam navigation. Working with 50 or 60 per cent. less of coal, we can make voyages that were once regarded as extremely difficult, if not impossible, and at the same time are enabled to carry a much larger cargo, inasmuch as less space is required whether for stowage of fuel, or for the engines and boilers.

Before leaving this subject I should mention my conviction that much may yet be done to produce steam power at a still cheaper rate, and I would call the attention of the younger members of our Institution to the immense benefits which must accrue to them and to the country by new and successful research in this direction.

Not very long ago experiments were made on a moderately large scale by injecting the common atmosphere into the boilers of a steam ship, and though the results were not altogether satisfactory, I am strongly impressed with a belief that further investigation may ultimately lead to success.

Digitized by Google

I may also mention that experiments which have been made on the Clyde, in order to expel the water and air which are formed in the condenser, may eventually enable us to save some of the power now absorbed by the air-pump, and as these improvements are directed to the vital portions of a condensing engine, they are well worth the serious attention of those who are interested in steam navigation.

Loss of Steam Vessels at Sea.

The ship itself being so closely allied to the engine, it may not be out of place to offer here a few remarks upon the loss of vessels, and to endeavour to account for the frequency of such calamities.

Every engineer must have noted comparatively recent records of the number of steam ships bound for the Baltic and the Mediterranean, and foundering during their passage of the North Sea and the Bay of Biscay. These accidents have frequently been attributed to overloading, but though I am a decided advocate for keeping a sharp look out in order to prevent this practice, I am obliged to confess that in a great number of instances overloading does not to my mind satisfactorily account for all such disasters.

It should be remembered that in gales of wind, steam ships of the present type are handled differently from sailing ships. So long as canvas will stand the pressure, the sailing vessel in a gale is placed under small sail and hove to, with her hatches closely battened down. This position, with careful attention to the helm and sails, enables the crew to ease the vessel up to any sea which may appear more than usually threatening. Thus she may be kept in comparative safety, even though her head may fall off occasionally by an unlucky or cross sea.

On the other hand, the mercantile steamer of the present day is built long and narrow, with large openings in the deck for engine-room skylights and stokehole. Her great length in proportion to her breadth, prevents her from being hove to, so closely as a sailing ship, unless she is helped with enough steam to keep her head up to the sea. Therefore any accident occurring to the engine is followed by the long steam ship falling off the wind, which has the effect of bringing her broadside to the sea. She is then exposed to the full force of the waves, and, before any repairs of the engine can be effected, the sea often breaks into the engine room, rises to the furnaces, puts out the fires, and leaves her helpless, or, at all events, only dependent on canvas which will not enable her to face the heavy seas. I am at a loss to understand how it is that such an obvious evil should have remained so long without a

Digitized by Google

remedy being provided to protect the vessel should the engines break down, especially as the cost would be inconsiderable. The engine and boiler rooms, containing what may be called the vital parts of steam vessels, should at least be as secure from an inrush of water as any other part of the ship; but the practice is to cover the skylights with glass protected by iron rods and canvas, so that the first heavy sea that comes on board breaks through.

If steam ships are to be protected from overloading—and it is very proper that this care should be exercised—why should not similar supervision lead us to considerably raise the engine-room combings—protect the skylights with a base formed of iron Venetian shutters for the canvas coverings to rest upon, and materially increase the size and height of ventilators, which might be made telescopic, so that in bad weather, when the skylights are closed—a good supply of air for the combustion in the furnaces may be easily and safely obtained. If these things be done, and at the same time care be taken that all the sea-cocks shall be absolutely in view, and accessible at a moment's notice, we shall assuredly hear of fewer steam ships foundering at sea.

Capital and Labour.

There is a subject to which I must allude, though the serious difficulties that present themselves whenever it is fully discussed prevent my entering upon it at any length on the present occasion. I refer to the mutual relations of Capital and Labour, and to the disturbed condition of what is called "The Labour Market."

This topic has been constantly before the public for the last few years, and may be said to be of vital importance to the whole community. It necessarily affects the estimates of all those who are engaged in the construction of public works, or who have invested capital in large manufacturing enterprises; it also affects, as directly, the vast number of workmen employed, but the results of a disturbed state of the labour market do not stop there.

They extend to dealers in commodities and to consumers of articles of daily necessity, the prices of which are ultimately regulated by profits or wages, so that the present uncertainty of market prices, and the consequent suffering of a large part of the population, is to a great extent caused by the equally injurious uncertainty of the price of labour and the profits on capital. I cannot, of course, presume to attempt any complete solution of difficulties that vary according to the special conditions of each particular industry, but I may be permitted to offer a few remarks on the

Digitized by Google

effects of the unsettled state of labour on mining and mechanical works such as those which I am called upon to direct.

Let me at once admit, that, in my opinion, the workman has a just right to sell his individual labour for its highest value. It is only by acknowledging this right that we can assert the equally obvious claim of the employer to regard that labour as one of the necessary commodities which he has to buy, and to obtain it as cheaply as may be possible. I am not discarding the notion that there may and should be another element in the relation of employers and employed. Doubtless there should exist a mutuality of sentiment, which, where it is present, has a very powerful influence in uniting masters and men. But it must not be forgotten, that in order to do this the sentiment must be really mutual, so that the result will be an intelligent regard for each other's interests. Such sentiments of reciprocal regard and good-will may follow when each party concerned allows the just claims of the other;—when employers are willing patiently to listen to reasonable requests, and are not too ready to refuse all concessions, even though they may be warranted by circumstances;—when workmen are both willing and able, fairly to estimate the position of employers, at times of keen competition or of slack demand, and to abate pretensions to increased pay or diminished hours of labour, if either one or the other involve immediate serious loss and the depression of an entire industry.

At present, however, we have to deal, not with the possible sentiments, but with the hard facts of the case. The effect of recent combinations of workmen has been to deny the just right of employers to regard either wages or labour as a commodity. At the same time, it is constantly affirmed that those who have labour to sell are entitled so to regard it, and to insist on selling it dearly, or even at a factitious price. This distorted view of the question leads workmen to regard with extreme jealousy and dislike any appearance among employers of that combination to which they themselves constantly resort. Let us suppose, however, that all the employers engaged in a particular industry were to combine for the purpose of obtaining high prices, just as workmen do for obtaining high wages.

Let us suppose they were to do so at a time when large contracts for important works had to be given out. If they were to follow the line of those whom they employ they would agree absolutely in fixing the amount of their tenders for those contracts, and the Company issuing them would be entirely in their hands. But let us go a step further, and imagine masters, not only adopt-

Digitized by Google

ing the principle of combination, but actually combining with the workmen who had already fixed the amount of wages throughout an entire district. The result would be that masters and men together could, theoretically, fix any price that they chose to demand for works of every description.

Such an illustration appears so extreme as to amount to absurdity; but it at least shows what would be the result of combination carried to a complete issue. I ought to apologize for stating so obvious a proposition, but I desired to arrive at the equally obvious fact that competition is the real antidote for combination. In manufacturing and mercantile affairs competition is inseparable from progress and general improvement.

In many cases tenders must be sent in some months before the period for commencing the work. Should that work be such as the manufacturer is in the habit of supplying, the usual method of estimating prices is simple enough. He adds to, or deducts from, the amount of outlay, as calculated from the last transaction of the same kind, the sum which represents the difference in the present cost of material and wages, and to the amount thus obtained adds the proposed profit on the transaction. It is easy, therefore, to see how a subsequent demand for increased wages may turn into loss profits calculated on contracts that will possibly be twelve months or more in course of completion.

It is this continued insecurity which is now seriously affecting some of our great manufacturing industries. A master who ventures to demur to a demand for higher wages is likely to be the victim of a strike which will entail still heavier losses; and this consideration may cause him to yield, notwithstanding that competition, and the already enhanced cost, and restricted hours of labour, may, at the best, have left him only a trivial return on capital, plant, and machinery.

It can scarcely be wondered at that this state of things should perpetuate bitterness of feeling. It is not surprising either, that the master who yields to exorbitant demands in order to save his contracts, and finds that he has for months to brood over his losses, is apt to remember his enforced concessions when he is more free to refuse what may be juster claims.

The constant recurrence of strikes, and the uncertainty of the labour market, have, in fact, changed the course of business, and undermined all systems on which contracts were formerly entered into, without leaving room for any settled plan to take their place.

Digitized by Google

Forward contracts for materials can no longer be readily secured; the cost of wages, which is one of the most important calculations in estimating profits, cannot be determined, and within a few days, or at a fortnight's notice, a master may find his capital lying idle, his machinery unemployed, and his whole factory an unremunerative investment.

This, then, is the present position of employers and employed towards each other; but I am bound to confess that it would be unfair to cast all the blame upon the men. In this, as in almost every conflict between persons who have learned to regard each other with suspicion, there are faults on both sides. It cannot be denied that "temper" has been a very potent element in causing and prolonging some of the larger strikes with which the country has been afflicted. In such disputes the main points of discussion are too often lost sight of, because of the desire of each party to "gain the day." So long as this feeling exists, so long will strikes continue. While masters and men have no confidence in each other, the men will periodically abandon work and fall into poverty and want, while masters will have to look at silent workshops.

This subject has occasioned me much painful thought in relation to several works over which I have control, and where I find that the endeavour to sustain satisfactory relations with a large number of workmen is by no means the least of the responsibilities. That mutual confidence, which is, in my opinion, essential to truly successful work in manufacturing enterprises, seems to be further and further from realisation; for some of the rules laid down by Trades Unions are incompatible with justice—not only to the masters, but to the men themselves. How can it be otherwise when the ingenious, skilled mechanic can only demand the same rate of pay which is the wage of the unskilful workman? The union rate of wages is fixed without regard to the ability of the worker to produce, either in quantity or in quality, labour that shall be of higher value to his employer. There is no need to point out how inconsistent this system is, with the constant (and true) assertion, that labour is a commodity. What should we say—what would the workmen say—if any combination of dealers ordained a level and unyielding value for commodities—for food, drink, and clothing—without regard to their true worth, or the conditions of supply? The result of this arbitrary control of wages is, that good workmen, who are compelled to receive less than they are worth, naturally regard their position as being unsatisfactory, and their advantages as valueless.

The denial of the right of masters to pay, and of men to

Digitized by Google

receive, higher wages for a better class of work, or for a larger quantity of labour performed by those who would rather remain at their business than waste their time—is a great evil for workmen in manufactories. A scarcely less miserable effect of the demand that labour shall be paid for without regard to quality, is the tendency to deterioration in the work itself. A good workman must have a very decided sense of responsibility to induce him to take as much pains with the work he turns out as he would do if he knew that he would obtain a reward in proportion to his display of ability; especially when he knows that the man next him is (through incapacity) turning out inferior work, and yet can demand as high wages as he is himself receiving.

And we must remember that the uncertainty of the demand for wages, and the consequent necessity of adding a sum of money to contract prices in order to meet possible contingencies, in case of strike, give a premium to foreign competition; while any deterioration in British workmanship removes the only advantage which we are able to claim in comparing our own and foreign productions.

To this point I directed special attention in a letter which was read to the workmen at Newcastle in 1871, and the statement I then made has, I regret to say, been more rapidly verified than I predicted; by the experience of manufacturers in their competition with foreigners, and by my own observation while I have been abroad, of the great increase of foreign engineering and shipbuilding works in places which recently depended on this country for their supplies.

With reference to that other vexed question—the reduction of the hours of labour, I can speak only in relation to my own experience. I believe, however, that I shall be supported by the experience of others engaged in large manufactures, when I express the opinion that in the long struggle which took place in the North, in the early part of 1871, the opposition of the masters was directed less to the shortening of working hours per day, than to the loss of time which they foresaw would ensue; for they knew by experience that the ability to earn the same amount of wages in shorter hours would increase the tendency to make "idle time." It is as they feared, for the effect of diminishing the hours of daily labour has been also to diminish, in a greater proportion, the quantity of work produced, so that machinery and floating capital have suffered loss, by frequently lying unproductive, even during those hours when the men are supposed to be at work. Thus it is frequently the case that a rise in wages produces

Digitized by Google

no real increase of earnings, and is of no actual benefit either to the men or to their families.

It is for the want of knowing what are the true effects of some of the changes demanded and conceded that the general public cannot duly estimate the relative position of employers and workmen during the conflict which precedes, and the crisis which follows a strike. For instance, at the time that the so-called "nine hours movement" was the assumed basis of the men's demand, it was generally supposed by the public that mechanics and labourers in engineers' shops were actually working fifty-nine hours a week. It is true that these were the hours fixed by the masters and agreed to by the men, but, as a matter of fact, they were seldom really worked, and in many large establishments it is well known that the average of working hours per week were actually fewer than would have been represented by nine hours a day, or the fifty-four hours per week, which the men demanded.

These disturbed relations of labour and capital are among the most difficult, and, at the same time, the most important questions to which those who are engaged in engineering work have to address themselves. Important, because they stand related, not only to the material of our national wealth and enterprise, but to the well-being of hundreds of thousands of our fellow-countrymen. Difficult, because they have to do,—not with mechanical operations, nor with inventions for directing and adapting vast physical forces; but with the sentiments, the duties, the prejudices, and the responsibilities of working men.

I wish that it was in my power to offer a solution even of the least of these difficulties. I am convinced that none can be found in the combination of class against class, or in the "defensive" policy which always ends in aggression.

While the representatives of each side are combining and encouraging each other to resist encroachments, or to do battle for supposed advantages, which may after all be disastrous alike to capital and to industry, there is a great and persistent invasion by foreign competitors, who, knowing more of economic science, or being less under the dominion of "Unions," are thus enabled to carry off the spoil.

Doubtless the spread of better and truer education may help to remove errors which keep up a ruinous antagonism between those who are mutually dependent; but it will be only after many years, and in another generation, that this irresistible force will achieve its results. We must endeavour in the meantime, while

Digitized by Google

we are promoting the spread of knowledge, to lessen evils which lie at the root of the mischief that we deplore.

It would be useless to conceal the fact that the unsatisfactory condition of the labouring classes, their social position, and their failure to profit by the claims which they have combined to secure, is to be attributed to the abuse of a luxury to which, in moderation, every working man is entitled. This is why no shortening of working hours, no increased rate of pay, obtains for them and for their families the advantages that should be derived from the greater leisure for self-culture and the improved means of making comfortable homes.

Till this great evil be mitigated, there is no hope for that improved condition of the working classes for which our legislators are looking. The mischief must be dealt with at its root. Increased means of instruction, better houses (provisions I strongly advocate), do not touch the question for the present generation. The men themselves have the cure in their own hands, and it can only be effected by their own strong determination to stamp out the cause of so much unhappiness.

If this should be effected, we shall have genuine sympathy and mutual confidence between masters and workmen, instead of continued ill-feeling. The settled working hours will be more regularly observed. Plant, capital, and machinery, which can only pay whilst employed, will be better utilised By moderation in living, the physique of the men will be improved, they will be able to earn more wages "by time," and the masters will be able to afford higher pay. They will have the means of providing healthier and happier homes, and, by the increased and regular economy of time and capital, will enable manufacturers to produce their commodities at a rate which will put this country in a position to meet foreign competition.

I do not speak bitterly, but in sorrowful earnest; and I know that there are a large number of good men to whom these remarks will not apply. Let me say, therefore, that it behoves us, who have had superior opportunities, better culture, more immediate means of surrounding ourselves with refining influences, to prove that we are, at least, learning to overcome prejudices, and patiently to take every reasonable method of proving to the men whom we have to employ that we entertain no animosity against them.

These results, however, can only be attained by forbearance. Let those who think themselves most aggrieved be the first to practise patient hearing and temperate acting; for these will be

Digitized by Google

the best claims for being listened to when the time comes either for asking reasonable concessions or for refusing inordinate demands.

Imperfectly as I have touched some of the most important topics which at present engage the attention of our profession, I am compelled to omit many others, perhaps equally important.

Unless I were to extend my remarks to such a length that I could scarcely hope for your kind attention, it would be impossible for me to enter upon such subjects as those of the enormous advances of telegraphic engineering and electric science, both of which are still making such vast strides that they form a distinct, though not an altogether separate, branch of our profession.

Amidst the number and variety of the great works yet to be effected for the benefit of mankind, every member of the profession has "verge and scope enough;" and if I have succeeded in bringing before you a few important subjects which may claim your earnest after-thought, I shall have increased reason to be glad that you have honoured me by placing me in the position which I now occupy, and that your courtesy has enabled you to hear me with an attention for which I heartily thank you.

Being duly moved and seconded, it was

RESOLVED—That the President be requested to permit his Address to be printed and circulated with the Minutes of Proceedings.

Digitized by Google

January 18, 1876.

GEORGE ROBERT STEPHENSON, President, in the Chair.

No. 1,443.—"The Ventilation and Working of Railway Tunnels."[1]
By GABRIEL JAMES MORRISON, M. Inst. C.E.

THE inconvenience and discomfort frequently experienced from imperfect ventilation in underground railways, and occasionally in the long tunnels under the Alps and in America, have led many to fear, when contemplating the proposed construction of still longer tunnels, that if the traffic be large, they may be a source of danger to health, and possibly to life. These apprehensions are not altogether groundless. In December 1872 the men on the engine of a goods train in the Mont Cenis Tunnel fainted, from the foulness of the air, and a serious disaster was narrowly averted. The traffic has since been worked without accident; still there is generally a feeling of relief at the termination of the underground journey, and the question is frequently asked, how tunnels of greater length will be ventilated. The usual answer is that they may be ventilated like mines; but although the general principles of underground ventilation are well understood, as the ventilation of railway tunnels has not yet, it is believed, been exhaustively treated, this Paper is offered as a contribution to the subject.

The proper ventilation of any space occupied by human beings consists in the regular supply of so much fresh air that the impurities occasioned by exhalation may never exist in proportions injurious to health or unpleasant to the senses. The subject may be conveniently divided as follows:—

1st. Fresh air, its composition and properties.

2nd. The impurities generated in railway tunnels, and their probable amount.

3rd. The proportion in which these impurities may be allowed to exist in any space occupied by human beings.

4th. The quantity of fresh air that must be supplied to railway

[1] The discussion upon this Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

Digitized by Google

tunnels, according to their length and to the traffic through them, and the best method of introducing it artificially, when natural ventilation cannot be relied upon.

I. Fresh Air, its Composition and Properties.

Pure air consists, approximately, of 23 per cent. of oxygen and 77 per cent. of nitrogen, weight for weight—or 21 per cent. of oxygen and 79 per cent. of nitrogen, comparative volumes:—but, in addition, the atmosphere always contains carbonic acid, so constantly, that it is questioned whether this gas be not a necessary constituent. The quantity is very small, for Dr. Angus Smith states that on the hills in Scotland the proportion was found to be 3·3 per 10,000; in the open parts of London 3 per 10,000, and in London streets 3·8 per 10,000.[1] In this Paper fresh air will be considered to contain $3\frac{1}{2}$ parts of carbonic acid in 10,000 parts; and the temperature of 60° Fahr. will be generally adopted, at which temperature the weight of a cubic foot of air is 0·0765 lb.

The specific gravity of air being	1
That of oxygen is	1·1
„ nitrogen	0·97
„ carbonic acid	1·52

Carbonic acid consists of 6 parts by weight of carbon and 16 parts by weight of oxygen: the volume is the same as that of oxygen. This gas is therefore $\frac{6}{16}$ heavier than oxygen.

II. The Impurities generated in Railway Tunnels, and their probable Amount.

When ordinary locomotives are used, the combustion of the fuel produces carbonic acid, carbonic oxide, sulphurous acid, and water, by the combination of the various component elements with oxygen. This last-named element has to be supplied by the atmosphere, which therefore becomes deficient in oxygen to a corresponding extent. The steam allowed to escape from the engine will also, at least in part, be found in the atmosphere of the tunnel in the form of aqueous vapour; but, being merely added to the atmosphere, does not render it deficient in oxygen. In addition, whether locomotives are used or not, the air is deteriorated by the breathing and organic exhalations of the passengers; and possibly

[1] "Air and Rain." By Robert Angus Smith. 8vo., London, 1872.

Digitized by Google

gases may also be given off by the ground through which the tunnel passes.

As to the impurities generated by the combustion of fuel:—whether complete or incomplete, the combustion of 1 lb. of carbon generates 31½ cubic feet of noxious gas; in the former instance this will be carbonic acid containing 31½ cubic feet of oxygen, and in the other carbonic oxide containing 15¾ cubic feet of oxygen. Carbonic oxide has not been found in appreciable quantities in the air of the Metropolitan railway.[1] It is an extremely poisonous gas, and even in small quantities would be very injurious. A certain amount of carbon is doubtless given off unconsumed. The proportion cannot be estimated, as it depends on the quality of fuel and the firing.

One pound of sulphur combining with 1 lb., or 12 cubic feet, of oxygen, forms 12 cubic feet of sulphurous acid weighing 2 lbs. Therefore, in the combustion of 100 lbs. of fuel containing 1 per cent. of sulphur, 12 cubic feet of sulphurous acid will be generated; and more or less in proportion to the percentage of sulphur. One pound, or 190 cubic feet, of hydrogen unites in burning with 8 lbs., or 95 cubic feet, of oxygen, and forms 9 lbs. of aqueous vapour. Its specific gravity is 0·625, air being 1. It can only exist by itself at a temperature exceeding 212° Fahr., but is absorbed by the air at lower temperatures in quantities varying with the temperature and pressure. As it is a harmless vapour, the quantity is unimportant.

Next to be considered is the steam or aqueous vapour given off from the engine. Each pound of carbon will evaporate at least 8 lbs., or 0·128 cubic foot, of water, forming steam having at 212° Fahr. a volume of 210 cubic feet. Each pound of hydrogen will evaporate 30 lbs. of water, forming steam having at 212° Fahr. a volume of 777 cubic feet. The steam is merely added to the atmosphere of the tunnel, and does not rob it of oxygen; any excess will be deposited on the surfaces of the tunnel and the train.

The total amount of the organic exhalations cannot be stated exactly, but it is almost infinitesimal compared with the impurities caused by the locomotive. One pound of coal per mile would be equivalent to more than five hundred persons. It is quite impossible to estimate the fuel within such narrow limits: therefore no notice need be taken of the effect of human beings and other

[1] Report on Air of Metropolitan Railway. See "Engineer," November 1, 1867.

Digitized by Google

animals upon the air, until the case of tunnels worked by other means than the ordinary locomotive comes to be considered.

The last point is the gases given off by the ground through which the tunnel passes. It is possible, that in the case of city railways, there may be slight infiltrations of ordinary coal gas; but after careful search none was found in the air of the Metropolitan railway. It is possible, also, that in strata containing large quantities of either fire-damp (hydrogen) or choke-damp (carbonic acid), these might find their way into the tunnel. They have, however, never been known to exist in appreciable quantities in any existing railway tunnels.

III. The Proportion in which these Impurities may be allowed to exist in any space occupied by Human Beings.

On this point there is no better authority than Dr. Angus Smith. Speaking of ventilation in houses he says:—

"Although the only impurity in air is not carbonic acid, as a rule the most convenient chemical test for ventilation of rooms rendered impure by exhalations from the person is the presence and quantity of this gas."[1] And he is of opinion that if enough fresh air be introduced to keep the proportion of carbonic acid at a certain point, it will be sufficient to reduce the proportion of organic exhalations to an amount neither unpleasant nor unwholesome. But he further says respecting carbonic acid:—"I have always considered it as remarkably innocent in small quantities, and been accustomed to look on the organic substances as the real evils; but the experiments in the close chamber have so far changed my mind, that I am inclined to think that carbonic acid has an injurious influence in small amounts."[2] He made several experiments on the effect of breathing air tainted with carbonic acid. The results on the pulse, &c., were similar whether the carbonic acid was pure or accompanied by a corresponding amount of organic matter. He appears to be of opinion that carbonic acid is one of the most, if not the most, dangerous impurity; and in the case of mines, as well as in that of houses, he takes its presence and quantity as the principal test of the quality of the air. He also made several experiments on the effect of a diminished quantity of oxygen, but generally in cases where the oxygen had been abstracted in the generation of carbonic acid.

---

[1] "Air and Rain," p. 192.

[2] *Ibid.*, p. 179.

Digitized by Google

By actual experiment, Dr. Smith found the following proportions of carbonic acid present in the atmosphere:—

	Parts by Volume of Carbonic Acid in 10,000 Parts of Air.
In streets of Manchester during fog	6·8
„ dress circle, Haymarket Theatre, 1864	7·6
„ close buildings (average)	16·0
„ Theatre Royal, Manchester, pit	27·3
„ worst parts of theatres	32·0
„ mines (average of 339 experiments)	7·85
„ „ largest amount	273·0

In all these cases the carbonic acid had been formed by combination with the oxygen of the air, and therefore represented an equal deficiency in the oxygen; and it was accompanied by a proportionate amount of organic and other noxious exhalations. Dr. Smith has come to the conclusion that in houses there should not in every 10,000 parts of air be more than 7 parts of carbonic acid, accompanied by a proportionate amount of organic and other exhalations, although in the evening 10 or more parts are often met with in sitting-rooms.

The carbonic acid to be considered will, instead of organic exhalations, be accompanied by sulphurous acid, aqueous vapour, and unconsumed carbon. It has been seen that carbonic acid is itself the dangerous element, and it is not possible, if Dr. Smith's views be accepted, to adopt a proportion much higher than he does: but as aqueous vapour and unconsumed carbon are certainly not more injurious than organic exhalations, there is no need to take a lower one, unless in any particular case there should be an excess of sulphurous acid. The mean between 7 parts, which Dr. Smith considers the utmost allowable in houses, and 10, about the average found in sitting-rooms in an evening, is 8½ parts. The maximum ever found on the Metropolitan railway was under 13 parts per 10,000, and the mean of four specimens taken at 4 o'clock one afternoon gave 8½ parts.

IV. The Quantity of Fresh Air that must be supplied to Railway Tunnels, according to their length and to the traffic through them, and the best method of introducing it artificially, when natural ventilation cannot be relied upon.

To prevent the subsequent parts of this Paper being misunderstood, it is necessary first to distinguish between natural and artificial ventilation.

In order to ventilate a tunnel artificially, sufficient fresh air

Digitized by Google

must be introduced to dilute the noxious gases, and so render them harmless: and the quantities hereafter arrived at in this Paper, as necessary for artificial ventilation, may appear exaggerated, because in existing tunnels the air is seldom very unpleasant, although fresh air is certainly introduced in much smaller quantities. But, in these cases, the result is obtained by natural ventilation and with a far smaller expenditure of power than if artificial ventilation were employed.

The vapour ejected from the locomotive may sometimes contain as much as 10 per cent. of carbonic acid. To reduce the proportion to $8\frac{1}{2}$ parts per 10,000 by the addition of air already containing $3\frac{1}{2}$ parts, 2,000 cubic feet of fresh air must be introduced for every 10 cubic feet of vapour.* But if the 10 cubic feet of impure air can be extracted, and replaced by 10 cubic feet of fresh air, a better result is obtained with $\frac{1}{200}$th part of the work. Now this is nearly what is effected by natural ventilation.

The vapour from the engine being hotter than the air and consequently lighter, an impure stratum of air finds an exit at the ends of the tunnel at the top, while fresh air enters at the bottom, and thus the tunnel is kept tolerably clear and wholesome by an interchange of air, which would not have any appreciable effect if thoroughly mixed with the products of combustion.

Figs. 1 and 2, Plate 1, are intended to illustrate the difference between natural and artificial ventilation.

From this it is evident that, as a general rule, natural ventilation should not be tampered with unless it be necessary to entirely supersede it by artificial ventilation. In those rare cases where natural ventilation takes place by the air entering at one end and going out at the other, or by entering at both ends and finding an exit by a shaft, the current may advantageously be assisted by artificial means; but wherever a double current is found at the ends of a tunnel, natural ventilation should not be interfered with unless it prove totally inadequate, because it will probably be necessary to introduce more than twenty times as much air artificially to obtain an equally good result.

The next point to determine is how much air must be admitted into a tunnel to keep down the impurities to a harmless proportion. Take the case of a locomotive burning 35 lbs. of carbon per mile in the shape of coke. Where ordinary care is taken to keep down the consumption of fuel, the goods trains will probably burn more, and the passenger trains less, and if there be an incline the trains in one direction will use more than in the other, but probably 35 lbs. will be a fair average. As each lb. of carbon will generate $31\frac{1}{2}$ cubic

Digitized by Google

feet of carbonic acid, the amount evolved per mile will be 1,102 cubic feet. If there be 1 per cent. of sulphur in the fuel, then 0·35 lb. will be burned per mile, and will give rather more than 4 cubic feet of sulphurous acid. The 35 lbs. of carbon will evaporate $35 \times 8 = 280$ lbs. of water, forming a volume of 7,350 cubic feet of steam at a temperature of 212° Fahr., or 5,770 cubic feet of aqueous vapour at 60° Fahr. The sulphurous acid is then only $\frac{1}{266}$ part of the carbonic acid, and consequently, when the latter rises to 13 parts in 10,000, the former will only be 1 part in 200,000. This amount is scarcely discoverable by the most delicate tests, and is certainly not directly injurious to health; it is quite perceptible to smell and taste, and is therefore unpleasant, but is only indirectly injurious by affecting persons with delicate throats. Assuming every 10,000 parts of external air to contain already $3\frac{1}{2}$ parts of carbonic acid, and the allowable proportion to be $8\frac{1}{2}$, it will be necessary to introduce 10,000 cubic feet of fresh air for every 5 cubic feet of carbonic acid generated; and for each train mile there must be admitted 2,204,000 cubic feet. A tunnel 26 feet wide and 21 feet high has a sectional area of 473 square feet, therefore the air admitted would fill 4,660 feet, or about $\frac{7}{8}$ mile; so that whatever the length of the tunnel, it must be filled with fresh air seven times for every eight trains.

Take the case of locomotives burning 24 lbs. of carbon per mile. This will correspond to those cases in which all or almost all the traffic is passenger traffic. Twenty-four lbs. of carbon give 756 cubic feet of carbonic acid, and to reduce the proportion to $8\frac{1}{2}$ parts per 10,000 of air, already containing $3\frac{1}{2}$ parts, there must be introduced 1,512,000 cubic feet, and in the tunnel having a cross section as above, this would fill 3,197 feet, or about $\frac{3}{5}$ mile; in other words, the tunnel should be filled three times for every five trains.

The above examples show the ventilation necessary to keep down the carbonic acid to the limit of $8\frac{1}{2}$ parts per 10,000.

That the consumption of each lb. of carbon gives $31\frac{1}{2}$ cubic feet of carbonic acid is a fact. That $8\frac{1}{2}$ parts per 10,000 is the limit to be allowed is only an opinion, although good grounds appear for holding it; still it cannot be insisted on as if this limit had been determined by experiment.

Now consider the case of frequent trains through short tunnels, and examine whether natural ventilation will suffice. Suppose the locomotives to burn on an average 24 lbs. of carbon per mile; but that, as advantage is taken of the stations and open spaces to get up the fire, only one-half, or say 12 lbs. per mile, are

Digitized by Google

consumed underground. In this case 378 cubic feet of carbonic acid will be evolved, and, if the fuel contain 1 per cent. of sulphur, about 1½ cubic foot of sulphurous acid. The amount of steam ejected will not be large, because in this case it would be in great measure, if not wholly, condensed. Suppose that the carbonic acid rise to 13 parts in 10,000, at which point the sulphurous acid may be troublesome, but not dangerous. If the external air, containing 3½ parts per 10,000 of carbonic acid, be allowed to mix with the products of combustion, 10,000 cubic feet must be admitted for every 9½ cubic feet of carbonic acid generated: that is, for each train mile 397,900 cubic feet, which in a tunnel having 473 square feet section will fill a length of 841 feet, or rather less than ⅛ mile of tunnel: in other words, whatever the length of the tunnel, it must be filled with air once for every six trains. Therefore if twenty-four trains per hour pass through a tunnel ⅛ mile long, a continuous current of air must be maintained of 1⅓ mile per hour; and if the tunnel be ¼ mile long, the rate must be 2 miles per hour. It is unlikely that natural ventilation would produce a current of 1½ mile or 2 miles per hour; but it will be safe to assume that in tunnels ½ mile long natural ventilation will suffice, provided the openings at the ends of the tunnels are large enough for the double current alluded to.

It is difficult to obtain the facts with regard to the Metropolitan railway, in a shape available for general rules. If the tunnels were in longer lengths they would be worse ventilated; but whether, with the same number of trains per hour, there would be mere inconvenience or absolute suffocation, cannot be directly determined from any facts yet observed on that line. For instance, it cannot be said how much of the products of combustion are ejected in the tunnels; nor the effect of the numerous ventilating shafts. That these have been beneficial is clear, but to what extent, and what would be their effect in a larger tunnel, is questionable. A long series of experiments on some one section, say Gower Street to King's Cross, would be necessary in order to arrive at any useful result.

The case of this railway may, however, be examined to see if the results in any way confirm conclusions.

In 1867 attention was attracted to the state of the atmosphere on the Metropolitan railway by the death of a woman at one of the stations, occasioned, it was found, by natural causes; but during the investigation careful analyses were made of the air of the tunnels at different hours. In a report by Geo. H. Bachhoffner, Ph.D., Henry Letheby, M.B., and J. Whitmore, M.D., dated the

Digitized by Google

23rd of October, 1867,[1] it is stated that the air was analysed for sulphurous acid, carbonic acid, carbonic oxide, coal gas, and oxygen; that no sulphurous acid was found, although tests were used which would have detected 1 part in 100,000; that carbonic oxide and coal gas were barely discoverable, and that oxygen was not deficient.

The last statement must not be taken strictly. It probably means, no oxygen was wanting except that contained in the carbonic acid. The proper amount of oxygen was not then settled within 4 or 5 parts per 10,000, and can indeed hardly be considered so now.

With respect to the carbonic acid: on the 7th of September, 1867, at 4 P.M., four specimens gave respectively 5·7, 6·9, 9·1, and 12·7 parts of this acid in 10,000 parts of air. A large number of other specimens gave an average of 5·2 parts, the highest being 6·2 at 4 P.M. on the 10th, and the lowest 4·1 at 2 A.M. on the 3rd of September. The analysts state that the mere fact of sulphurous acid being tasted and smelt in the tunnel is no proof that it exists in dangerous quantities, as the senses will detect a perfectly harmless amount undiscoverable by chemical means. They conclude by saying: "From the foregoing facts, we are enabled confidently to state that the atmosphere of the Metropolitan railway is not unwholesome or injurious to health." In this conclusion the best authorities must support them, for with the fact that 20 to 30 parts of carbonic acid per 10,000 exist in many public buildings when crowded, it would be absurd to condemn the Metropolitan railway, where the maximum is under 13. At the same time the tunnels are sometimes decidedly unpleasant; and there is no doubt that if similar tunnels were made somewhat longer, or more contracted at the ends, the demand for artificial ventilation would be imperative; and were this adopted, it should certainly be on the basis of reducing the proportion of carbonic acid to 8 parts or 9 parts per 10,000. Since the date of these analyses, although the traffic on the Metropolitan railway has increased, and the fuel changed from coke to coal, the ventilation has been improved by opening up the stations and by constructing shafts, and probably the atmosphere is less tainted with carbonic acid than it was then.

With regard to the use of coal as fuel in the place of coke.

The only combustible matter in coke is carbon, and the result of its combustion is carbonic acid. Coal, on the other hand, contains

[1] "Engineer," November 1, 1867.

Digitized by Google

hydrogen, the heating power of which is much greater than that of carbon; there is therefore more heating power in 1 lb. of coal than in an equal weight of coke. The result of the combustion of the hydrogen is harmless watery vapour, but the smoke from coal always contains carbonic oxide.[1] Now, in producing carbonic oxide, the carbon has not done half its work; therefore extra fuel must be burned. There is also more chance of the formation of sulphurous acid. Probably, nearly the same amount of carbon will be consumed whether coal or coke be used; and, taking smoke and sulphurous acid into consideration, with the same traffic and the same means of ventilation, the use of coal will render a tunnel equally unwholesome and more unpleasant than coke.

The actual power to effect the movement of the air at the required speed, so as to reduce by artificial ventilation the carbonic acid to a certain proportion, will now be considered, and afterwards the best means of applying that power.

The friction of air varies as the square of the velocity multiplied by the pressure against the sides of the passage. This pressure being uniform, its total amount depends upon the total surface, that is, the length multiplied by the perimeter of the cross section. The force required to propel air through any passage is therefore equal to the square of the velocity into the total surface multiplied by the co-efficient of friction. It is more convenient to state the force in lbs. per square inch or per square foot, or as so many inches of water pressure; the above result should therefore be divided by the area of the cross section.

The best form of the formula for practical purposes of ventilation seems to be:

$$H = \frac{K\,V^2\,P\,L}{A},$$

where

H = head of pressure in feet of air of same density as the flowing air.
L = length of the pipe or passage in feet.
P = perimeter of cross section in feet.
A = area of pipe or passage in square feet.
V = velocity in thousands of feet per minute.
K = co-efficient of friction = 0·03.

This formula is perfectly general, and may be used for any fluid; H will always be the head stated in feet of the flowing fluid.

The pressure of 1 foot of air, at 60° Fahr., is 0·0765 lb. per

[1] "Air and Rain," p. 458.

Digitized by Google

square foot. The pressure of 1 inch of water is 5·2 lbs. per square foot. Therefore if it be desired to reduce any result in feet of air to its equivalent in inches of water, the process is simply to divide it by $\frac{0{\cdot}0765}{5{\cdot}2} = 68$.

For circular passages, taking D for the diameter, the formula becomes

$$H = K\,V^2 \times \frac{4\,L}{D}.$$

These formulæ are only applicable to passages whose diameter is small in proportion to their length. For short passages the length should be increased by about 50 diameters of the passage: thus the formula for circular passages becomes

$$H = K\,V^2 \times \frac{4\,(L + 50\,D)}{D},$$

and that for irregular-shaped passages,

$$H = K\,V^2 \times \frac{P\,L + 200\,A}{A}.$$

The value 0·03 is reduced from a formula explained by Mr. Hawksley, Past-President, in a discussion on the Ventilation of Coal Mines.[1]

In a Paper on the Ventilation of Coal Mines, read before the Geological Society of Manchester in 1862, Mr. Atkinson adopts the same formula as the Author, but gives a constant of 0·26881, or nearly ten times that of most authorities.[2] Mr. Atkinson gives a table of co-efficients depending on the material of which the passage is composed:—

Material.	Observer.	Co-efficient.
Burnt earth	Peclét	0·268
Galleries of coal mines . . .	Greenwell	0·254
Sheet iron (clean).	Peclét	0·067 to 0·105
Cast iron (old and tarred) . .	Giraud	0·048
Gas in pipes	Hawksley	0·030
Water in pipes	Eytelwein	0·030
Sheet iron (old and rusty) . .	Girard	0·027
Tinned iron	D'Aubuisson	0·025

In a discussion on Fans, Mr. Greenwell stated that the co-efficient of friction varied according to the nature of the sides of the passage,

---

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. vi., p. 192.

[2] Quoted also by C. Cope Pearce in the Transactions of the South Wales Institute of Mining Engineers, vol. v. The figures, however, are taken from the original.

Digitized by Google

as shown by Girard, D'Aubuisson, &c.[1] To this Mr. Hawksley replied that these discrepancies arose from badly-conducted experiments; he had had good opportunities of making experiments in mines with long uniform airways, as well in pipes, and there were not in reality any such differences of co-efficients. On another occasion[2] Mr. Hawksley said that, when the density of any elastic fluid did not materially vary throughout the length of the pipe, the same rule as for inelastic fluids applied, and that the general formula was

$$V = 48\sqrt{\frac{h\,d}{l}}.$$

V being the velocity in feet per second; this formula, reduced to the form adopted by the Author, gives a constant of 0·031. From Eytelwein's formula according to Beardmore the Author deduces 0·028 as the constant. In a Paper by Mr. Lowe the constant is given as 0·030, and in an old formula, possessed by the Author for many years, the constant is given as 0·028. From experiments on the pneumatic tube from Euston to Holborn,[3] taking the velocity of the air to be that of the carriage, allowing nothing for the work done in moving the carriage, a maximum value is obtained of 0·036, and making allowance for the weight of the carriage, the results give a probable value for the constant of 0·027. The experiments in Lime Street tunnel are not well suited for deducing a constant,[4] the length, 1,200 yards, being hardly as great in proportion to width as is desirable. From the data given, making use of the formula for short passages, the constant comes out 0·049; but the velocity of the air may have been higher than taken: a difference of 20 per cent. would bring the constant to the same figure as the others. From experiments made at Crewe, shortly before the ventilation of this tunnel was carried out, the following formula was deduced:—

$$\text{Discharge in cubic feet per hour, } 1{,}314\sqrt{\frac{d^5\,h}{l}};$$

d = diameter of pipe in inches, h = head in inches of water, l = length in yards. This gives a constant for the formula adopted by the Author, of 0·029. The Author believes that the authorities quoted are sufficient to justify him in adopting 0·03 as the value of the constant K.

---

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxx., p. 304.
[2] *Ibid.*, vol. xxxiii., p. 53.
[3] "Engineering," 23rd Aug., 1872.
[4] *Vide* Inst. Mech. Eng., Proceedings, 1871, p. 22 *et seq.*

Digitized by Google

It will be convenient now to consider the best position for applying the power, so as to insure the supply of a proper amount of fresh air.

The most obvious arrangement is to withdraw the air from the centre of the tunnel. Where this method is applicable no other can compete with it; no valves or doors are required; the air enters at both ends of the tunnel; and the speed of current necessary for ventilation is therefore only half what it would be if the current entered at one end and passed out at the other.

This system has been adopted at Lime Street tunnel, Liverpool. The tunnel is 2,025 yards long, and the air in it is entirely changed in eight minutes: 431,000 cubic feet are withdrawn per minute, and the resistance of the tunnel is so slight that a partial vacuum of 0·14 inch of water is sufficient to cause this; indeed, almost the whole of the power appears to be expended in overcoming the friction of the air in the shaft. The case is somewhat peculiar. There is a considerable incline, and therefore the heavy (that is to say, the coal-burning) traffic is in one direction only. The fan is placed in a shaft 1,212 yards from the lower end of the tunnel. As soon as a train is ready to start, the fan is set in motion. The train takes three minutes to run through; the lower portion of the tunnel is entirely cleared in five minutes, and the upper portion in four and a half minutes from the time the train reaches the top of the tunnel. The fan is only worked when required: when not at work the tunnel clears itself by natural ventilation in forty-five minutes. In the case of short tunnels, with frequent trains, or of long tunnels with a smaller number of trains, this intermittent system would be inapplicable.

A tunnel ½ mile long, with thirty trains per hour, would represent the worst cases on the Metropolitan railway. If artificial ventilation were adopted, all the products of combustion must enter the tunnel. At a shaft near the centre of the tunnel, all the air might be drawn from the stations, which would then be constantly full of fresh air, and the passengers on the platforms would never feel any discomfort. Supposing, as in the second example given above, a consumption of 24 lbs. of carbon per train mile, to bring the amount of carbonic acid down to the proportion of 8½ parts per 10,000, the tunnel must be filled three times for every five trains, or eighteen times per hour; as the tunnel is ½ mile long, and is filled from both ends, the velocity of the current will be nearly 400 feet per minute, and there must be withdrawn $473 \times 400 \times 2 = 378{,}400$ cubic feet per minute. This is less than the duty of the fan at the Lime Street tunnel.

Digitized by Google

The head of pressure is:—

$$H = K V^2 \times \frac{P L + 200 A}{A}$$

$$= 0{\cdot}03 \times 0{\cdot}4^2 \times \frac{83 \times 1{,}320 + 200 \times 473}{473}$$

$$= 2{\cdot}07 \text{ feet of air} = 0{\cdot}03 \text{ inch of water.}$$

As probably a head of $\frac{3}{4}$ inch of water, or 3·9 lbs. per square foot, will be required to force the air through the passages leading from the tunnel, the friction of the tunnel proper is not worth considering. Air to the amount of 380,000 cubic feet per minute withdrawn against a vacuum of $\frac{3}{4}$ inch of water represents an effective HP. of

$$\frac{380{,}000 \times 3{\cdot}9}{33{,}000} = 45.$$

At such low pressures, the effective power of a fan can scarcely exceed 50 per cent. of the indicated HP. of the engine, so that about 90 HP. will be required.

A tunnel 7 miles long, with sixteen trains per day, consuming on the average 35 lbs. of carbon per mile, would have to be filled once for each train, or sixteen times in twenty-four hours. This would require a current from one end to the other of 410 feet per minute; for, in the case of very long tunnels, it rarely happens that it is possible to have a shaft in the middle. In the Hoosaac Tunnel there is such a shaft, and of course if that tunnel were to be ventilated artificially, advantage would be taken of it; but, as a rule, long tunnels are constructed to overcome great natural obstacles, and are without a shaft from end to end.

Assuming the same size of tunnel as before, and taking the formula for long passages,

$$H = \frac{K V^2 P L}{A} = \frac{0{\cdot}03 \times 0{\cdot}41^2 \times 83 \times 36{,}960}{473},$$

$$= 33 \text{ feet of air} = \tfrac{1}{2} \text{ inch of water.}$$

If $\frac{3}{4}$ inch be allowed for the friction in the air-channels, it will give $1\frac{1}{4}$ inch pressure altogether. The necessary pressure in mines is often considerably higher; but even in what are considered properly ventilated mines, the air-passages are often so small that a man can scarcely crawl through them. If the number of trains be twelve per day, the average current to ventilate the tunnel will only be $3\frac{1}{2}$ miles per hour; and if a proportion of $13\frac{1}{2}$ parts of

Digitized by Google

carbonic acid per 10,000 be permitted, it will only be $1\frac{3}{4}$ mile per hour.

This case is roughly that of the Mont Cenis Tunnel.[1]

Considering the difference of temperature on opposite sides of the Alps, it is probable that the average current is more than this; consequently there does not seem to be any urgent need for artificial ventilation; but if the traffic should ever reach twenty trains per day, mechanical ventilation will most likely be a necessity. Even at present, although the average amount of carbonic acid sometimes rises to a high proportion in certain parts, this is not felt seriously by the passengers, who are exposed to such accumulations for a few minutes only. But with the workmen it is different, and therefore a pipe 8 inches in diameter has been laid through the tunnel,[2] into which air is forced, with cocks at intervals, to supply fresh air when necessary.

The Mont Cenis Tunnel was originally straight, but the approaches necessitated the construction of curved ends (Plate 1, Fig. 3). The unused portion of straight tunnel forms a capital place for the erection of machinery for ventilation. If, however, the air were extracted from the straight unused portion so as to create a partial vacuum of $\frac{1}{2}$ inch of water at the point where the straight and curved portions join, then there would only be a slight current through the main tunnel, and a strong one through the short curved portion. To get over this difficulty it will be necessary to employ doors. If properly interlocked with signals, there would be no more danger attending their use than there is in the working of many parts of the railway system.

This appears to be a case in which natural ventilation could be advantageously assisted by artificial means. The air travels naturally from north to south; if a shaft were sunk near the south end, provided with a fan or a furnace, and doors were placed across that end of the tunnel, the natural ventilation would be greatly assisted. It is probable that for such a purpose a furnace is more suitable than a fan (Plate 1, Figs. 4, 4A, 4B). A comparatively small expenditure would suffice to maintain the Mont Cenis, or any similar, tunnel in as good a state as it is when circumstances favour natural ventilation. If the traffic in such a tunnel increase to twenty trains per day each way, as the tunnel requires to be filled seven times for every eight trains, for forty

---

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxvi., p. 2. Exact length of the tunnel, 7·6 miles.

[2] *Ibid.*, vol. xxxvi., p. 18.

Digitized by Google

trains the air would have to be changed thirty-five times, necessitating a current of 10 miles an hour. The head required for a current of 10 miles per hour through a tunnel 7 miles long is given by the formula

$$H = \frac{K V^2 P L}{A} = \frac{0{\cdot}03 \times 0{\cdot}880^2 \times 83 \times 3{,}696}{473},$$

$$= 150 \text{ feet of air} = 2\tfrac{1}{4} \text{ inches of water.}$$

If $\frac{3}{4}$ inch of water be allowed for the friction of the air-passages, &c., the total head will be 3 inches of water, or 15·6 lbs. per square foot, and the HP. required

$$= \frac{473 \times 880 \times 15{\cdot}6}{33{,}000} = 197.$$

The effective power of a fan rarely exceeds 60 or 65 per cent. of the indicated HP. of the engine which drives it, so that an engine of about 325 HP. would be required.

It will be admitted that 10 miles per hour is the swiftest current that can be allowed. Consequently something like a limit has been reached; and it must be concluded that if the methods for working long tunnels continue to be the same as are now used in the open air, then, even with the aid of artificial ventilation, 7 miles is the longest tunnel that can be ventilated satisfactorily, to allow twenty trains each way per day, without inconvenience to the passengers. It may be desirable, however, to examine what can be done in other cases by the help of artificial ventilation.

Suppose the case of a tunnel 22 miles long, ventilated by a current of 10 miles per hour. The head required will be

$$H = \frac{K V^2 P L}{A} = \frac{0{\cdot}03 \times 0{\cdot}880^2 \times 83 \times 116{,}160}{473},$$

$$= 470 \text{ feet of air} = 7 \text{ inches of water.}$$

Allowing 1 inch for friction of air-passages, &c., the total head will be 8 inches, or 42 lbs. per square foot, requiring an effective HP. of

$$\frac{473 \times 880 \times 42}{33{,}000} = 530.$$

It follows that the indicated HP. of the engine would have to be 900. At one end the air will always be fresh, while at the other

Digitized by Google

it will be highly charged with deleterious gases. The amount of this difference can easily be stated for any given arrangement of trains. The average state of the foul end, supposing a consumption of 35 lbs. of carbon per train mile, will be as follows:—

Trains per Day in each Direction.	Total Trains per Day.	Parts of Carbonic Acid in 10,000 parts of Air.		Remarks.
		Excess over that found in Fresh Air.	Total Amount.	
6	12	5	8½	Pure and pleasant.
12	24	10	13½	Worse than any parts of the Metropolitan railway.
24	48	20	23½	This amount of carbonic acid is unpleasant even without smoke, and is decidedly injurious.
48	96	40	43½	Very offensive and unwholesome; much worse than the worst parts of the most stifling theatres and courts.

The following statements will show how the length of a tunnel affects the power necessary for ventilation. The figures refer only to the effective power required to overcome the resistance of the tunnel proper.

There are two cases:—

1st. When a definite velocity of current has been fixed upon.

2nd. When the amount of traffic and the allowable proportion of noxious gases are fixed.

In the first case, the head of pressure and the HP. required will both vary as the length.

EXAMPLE.—Velocity of air fixed at 10 miles per hour.

Length of Tunnel.	Velocity of Air.	Head of Pressure.	HP. effective.
Miles.	Miles per hour.	Inches of water.	
7	10	2¼	148
14	10	4½	296
22	10	7	461

In the second case, the velocity of the air will vary as the length;

Digitized by Google

and the head of pressure required will vary as the cube, and the HP. as the fourth power of length.

EXAMPLE.—Forty trains per day. Limit of impurity, 8½ parts of carbonic acid per 10,000. Fresh air required, 2¼ million cubic feet per train mile.

Length of Tunnel.	Velocity of Air.	Head of Pressure.	HP. effective.
Miles.	Miles per hour.	Inches of water.	
7	10	2¼	148
14	20	18	2,362
22	32	70	14,500

A glance at this table shows an impracticable state of affairs. In the tunnel 22 miles long a current of 32 miles an hour would keep down the average amount of impurity, but trains going in the same direction as the air would be enveloped in their own smoke, while those coming in the other direction could hardly make way against the force of the wind. In fact, long tunnels with a large traffic worked by locomotives cannot be properly ventilated.

It has been proposed, with a view to artificial ventilation, that two single-line tunnels should be constructed instead of one double-line tunnel. This point has been discussed[1] at considerable length, but with the exception of one remark by Mr. Sopwith, all the published statements seem to be founded on fallacious, or at least imperfect, views.

In a double-line tunnel, when the air is stagnant, the carbonic acid introduced by the passage of a train burning 35 lbs. of carbon per mile will amount to 4½ parts per 10,000. In a single-line tunnel, under the same circumstances, the impurity introduced will amount to 9 parts per 10,000.

With an air current of 10 miles an hour, the train travelling in the same direction at 30 miles an hour, the impurity given off in a train mile is compressed into ⅔ mile, and consequently the proportion of impurity introduced is 13½ parts per 10,000. Every train, therefore, is enveloped in an atmosphere containing an excess of 13½ parts of carbonic acid per 10,000 due to its own engine. If, on the other hand, the current of air be in the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxvi., p. 17 *et seq.*

Digitized by Google

opposite direction, the carbonic acid given off in 1 mile is diffused through $1\frac{1}{2}$ mile, and every train is constantly enveloped in an atmosphere containing an excess of $6\frac{3}{4}$ parts of carbonic acid per 10,000 given off by its own engine. In the first case, however, a succeeding train would enter a clear tunnel, while in the second it would enter a foul tunnel.

Examples are given (Plate 1, Figs. 5, 6) of a single-line tunnel ventilated by a current of air in the same direction as the trains, and of one ventilated by a current in the opposite direction to the trains.

Figures assumed in the example given:—

Length of tunnel	20 miles.
Sectional area of single-line tunnel	$236\frac{1}{2}$ square feet.
„ „ double	473 „
Consumption of carbon per train mile	35 lbs.
Velocity of air	10 miles per hour.
„ train	30 „ „
Traffic in single-line tunnel	1 train per hour.
„ double „ „	1 train in each direction per hour, trains starting at the same moment from both ends.

The figures show the carbonic acid given off by the fuel in parts per 10,000 of the air of the tunnel, *i.e.*, they give the excess of carbonic acid over that in ordinary fresh air. The instances of the two single-line tunnels show, clearly, that there is a great advantage in ventilating against the train. In the double-line tunnel both states of impurity shown in the single-line tunnels will exist together. But as the trains are supposed to run at regular intervals of one hour, and to start from each end at the same moment, the condition of the air will be much more nearly uniform than in either of the other illustrations (Fig. 7). The trains which enter at the foul end of the tunnel will not start till twenty minutes after the arrival of the trains from the other end, consequently the worst atmosphere will consist of a mixture of air containing an excess of 27 parts of carbonic acid per 10,000, with an equal amount of air containing an excess of $13\frac{1}{2}$, giving an average of $20\frac{1}{4}$. If the traffic be light, and there be only one train at a time in the tunnel, the advantage of a large tunnel is obvious, and the evil effects of irregular traffic will be much less felt in double-line tunnels than in single-line ones.

Very large amounts of carbonic acid have here been dealt with, but that does not affect the general question. The attempt has been made to show clearly that where a tunnel has to be artificially ventilated, by a current of air from end to end, no advantage can

Digitized by Google

be derived from making two single-line tunnels instead of the double-line tunnel.

Before adverting further to the question of the best methods of ventilating and working very long tunnels, a short account will be given of the various methods which have been employed for the purpose of creating a flow of air through underground passages.

The simplest plan is the furnace;[1] which at one time was the only system employed, and it is still used in many collieries. There is a good deal to be said in favour of its simplicity, but it is only in the case of very great depths that this system can compete for economy with mechanical methods, and even then there are various drawbacks. The useful effect rarely exceeds 5 per cent. of the actual energy given out by the coals, and although, at a colliery, this is often, but wrongly, considered a matter of minor importance, in tunnel ventilation it is of the first consequence.

One of the first mechanical ventilators was invented by Mr. Struvé, of Swansea.[2] It consists of a piston, somewhat resembling a gasometer, working in a brick chamber, in an annular space filled with water. The air is admitted by, and expelled through, flap-valves. It is well suited for extracting large quantities of air from collieries at pressures of 5 inches or 6 inches of water; but the large amount of clearance renders it unsuitable where the pressure is sufficient to cause a practical difference in the density of the air. The effective duty is stated to vary from 40 per cent. of the actual power put into the pump to 40 per cent. of the gross boiler power.

There is a pair of ventilators of this description at Cwm Avon,[3] with pistons 18 feet in diameter and of 7 feet stroke, working 8 strokes per minute. This machine exhausts from 40,000 to 56,000 cubic feet per minute, with a water gauge of 3 inches. A slightly smaller ventilator at Risca Colliery[3] exhausts 43,800 cubic feet per minute, with a water gauge of 2·3 inches.

Exhausters on a somewhat similar principle have been erected at the St. Gothard Tunnel works.[4] These are cylinders hung one

---

[1] *Vide* Inst. Mech. Eng., Proceedings, 1869, p. 133; and Trans. Inst. of Eng. in Scotland, vol. xiv., p. 72.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. x., p. 38.

[3] *Vide* South Wales Inst. of Engineers, vols. v. and vi., *passim*. Paper by C. Cope Pearce.

[4] "Engineering," 7th May, 1875.

Digitized by Google

at each end of a rocking beam, which alternately dip into annular tanks of water. The space to be ventilated is connected with these air-cylinders by pipes with inlet valves, and the tops of the air-cylinders are furnished with outlet valves. Each time the cylinder rises it fills with air from the pit or tunnel, which in falling it expels through the valves on the top. These exhausters are therefore single-action pumps, while Struvé's are double-action. They are intended to work with a water gauge of 6 inches, and their general design renders them suitable for much higher water gauges than Struvé's.

Lemielle's ventilator consists of a vertical drum, with movable leaves or vanes,[1] placed eccentrically in a casing, so that the leaves lie close against the drum on one side of the casing, but expand as they pass the other, and thus sweep out a certain amount of air at each revolution. There is a ventilator of this description at Page Bank Colliery,[2] Durham, 23 feet in diameter and 32 feet high. It usually works up to about 60,000 cubic feet per minute with a 2·6-inch water gauge, but occasionally to 97,000 cubic feet per minute with a 6·6-inch water gauge. The useful effect is 36 per cent. of the gross boiler power.

In some collieries the steam jet has been tried with success, as at Lower Moor Colliery,[3] Oldham. The apparatus consists of seventy-two vertical pipes 5 feet long and 7 inches in diameter, fitted to an iron frame on the top of the upcast shaft: into each is inserted a steam pipe having a nozzle $\frac{3}{16}$ inch in diameter, supplied with steam at 38 lbs. pressure. This rough apparatus exhausts 16,000 cubic feet per minute.

In the working of pneumatic tubes, between telegraph offices in London, the steam jet has been tested against a first-rate steam-engine;[4] at 40 lbs. pressure the engine does most work, but at 70 lbs. pressure the steam jet is superior. The nozzle, in this instance, is constructed in the most approved manner, and the vacuum produced is equal to 23 inches of mercury; but the Author does not know of any instance where, with a water gauge of a few inches, such good results have been obtained by a steam jet as by other means. The jet is probably ill suited for exhausting large quantities of air at low pressures.

---

[1] *Vide* North of England Inst. of Mining Eng., Trans., vols. xviii., p. 63 *et seq.*, and xix., p. 2. Steavenson on Mechanical Ventilation. Inst. Mech. Eng., Proceedings, 1858, p. 63.

[2] *Vide* Inst. Mech. Eng., Proceedings, 1869, p. 147.

[3] "Engineer," 19th Jan., 1872.

[4] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxiii., p. 16.

Digitized by Google

The best means of ventilation for tunnels seems to be the fan. It is used in collieries and mines throughout the world, and is the only machine that has ever been applied to tunnel ventilation.

The fan erected at Lime Street tunnel[1] is 29 feet 4 inches in diameter, 7 feet 6 inches wide, and runs at forty-five revolutions per minute; it is by no means of the most approved construction, but the circumstances of the case are peculiar: at times the tunnel ventilates itself through the fan, which is constructed to allow of this, the heat of the boiler fires assisting the natural ventilation. When the fan is at work the vacuum in the tunnel near the bottom of the shaft is only equal to 0·14 inch of water, but near the fan it is equal to 0·54 inch. When the air leaves the fan the pressure is equivalent to 0·19 inch of water above the atmosphere, this being the pressure required to drive the air through the chimney into the open air. The fan therefore seems to exhaust 431,000 cubic feet per minute, against a pressure of $0·54 + 0·19 = 0·73$ inch of water, which represents 50 HP. The actual indicated HP. of the engine is 134. When running at forty-four revolutions, but doing no work, the indicated HP. expended in the friction of the engine and machinery is 34. The effective duty of the fan is therefore only 37 per cent. of the gross power, or 50 per cent. of the net power. The effective duty of many other fans is, however, much higher.

The pneumatic tube from Euston to the General Post Office is worked by a fan in Holborn,[2] 3,080 yards from Euston. This fan is 22 feet in diameter, and is driven at the rate of one hundred and sixty revolutions per minute. The tube is tunnel-shaped, 4 feet wide and 4 feet 6 inches high. The usual speed of the carriage is about 15 miles an hour. As the tube has an area of 16·3 square feet, the discharge is 20,000 cubic feet of air per minute. The fan is arranged to work either for exhausting the air or for compressing it. At the speed mentioned the water gauge is about 10 inches,[3] and this shows a useful power of thirty-two horses.

The Metropolitan Railway Company have lately made use of this tube for the purpose of ventilating their tunnel.[4] The tube crosses the tunnel between Gower Street and Portland Road; and valves have been arranged so that, on each journey of the carriage

---

[1] *Vide* Inst. Mech. Eng., Proceedings, 1871, p. 24.
[2] "Engineering," 23rd Aug., 1872. "Engineer," 10th Nov., 1865.
[3] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxiii., p. 4.
[4] "Engineer" and "Engineering," 31st July, 1874.

Digitized by Google

from Euston to Holborn, as soon as the carriage passes the Metropolitan tunnel, the valves open, and the air is drawn from the Metropolitan railway instead of from Euston. But the tube can only be used when the fan is exhausting, and when the carriage is between the Metropolitan railway and Holborn; that is about once an hour for five or six minutes.

Of late years a great many fans have been introduced. One called the Guibal fan seems to give satisfaction.[1] The effective duty of some of them has been stated to be 83 per cent. of the actual power put into the fan shaft;[2] but generally it is not so high. In these fans the casing is concentric with the fan, and quite close to it, with only one opening, the size of which is regulated by a shutter. The chimney is funnel-shaped, to allow the velocity of air to be reduced before entering the atmosphere. The fact that so much of the circumference of the fan is useless for discharge would lead to the supposition that the quantity of air must be less than that discharged from other fans of equal size.[3] It seems, however, that the useful effect of these fans is high, and that, for any given discharge and water gauge, the Guibal fan will work with less coal than many others, and with as little as any.

There is a fan of this description working at Thirslington Colliery. It is 36 feet in diameter and 12 feet wide, and at eighty revolutions it will discharge 80,000 cubic feet per minute, under a water gauge of 6·2 inches. A somewhat smaller fan, at Gethin Colliery, discharges 153,600 cubic feet per minute, under a water gauge of 2·6 inches. It is stated by Mr. Wilkinson that he obtained 63,000 cubic feet of air per minute from a Guibal fan, with a similar amount of steam required for 40,000 cubic feet per minute with Struvé's ventilator.

On their first introduction fans were supposed to be applicable only to low water gauges; but it has been found that they will work economically up to high gauges for ventilating purposes. There are some at Grand Busson, near Mons, in Belgium, 30 feet diameter, working at one hundred revolutions per minute, with 7 inches water gauge.

To produce a current of air of 10 miles an hour through a

---

[1] *Vide* Inst. Mech. Eng., Proceedings, 1869, p. 78. North of England Inst. of Mining Eng., Trans., vol. xiv., p. 73. "Engineering," 9th April, 1875.

[2] *Vide* Inst. Mech. Eng., Proceedings, 1869, p. 152.

[3] Mr. Cowper seems to hold the same opinion. *Vide* Minutes of Proceedings Inst. C.E., vol. xxx., p. 258.

Digitized by Google

tunnel 20 miles long, a water gauge of less than 7 inches is required, or, including an allowance of 1 inch for friction in the air-passages, &c., 8 inches altogether; it is therefore evident that fans are suitable for the pressures required in all practical cases; and as they are better adapted for passing large quantities of air than any other ventilating apparatus, they should be employed in all cases where tunnels are to be ventilated artificially. The best fans appear to utilise more than 70 per cent. of the actual power applied to the fan shaft, or 15 or 20 per cent. less than the indicated power of the engine.

To sum up this part of the subject.

It has been shown that tunnels less than ½ mile long, with large open spaces at the ends, may be left to ventilate themselves, even when traversed by frequent trains at short intervals.

In tunnels somewhat longer, and even in short tunnels if the ends are very contracted and the traffic great, artificial ventilation would be beneficial, and in some cases necessary; but where employed it must be trusted to entirely; any partial mechanical ventilation does more harm than good.

In tunnels up to about 7 miles in length, natural ventilation may be trusted to, provided they are advantageously placed and the traffic is light, as in the Mont Cenis tunnel.

Lastly, with a heavy traffic of both passengers and goods, where the number of these trains reaches something like one an hour in each direction, a tunnel of 7 miles, without shafts, is about the longest which can be kept pleasant and wholesome, even by artificial ventilation, if ordinary locomotives be used. But it does not therefore follow that longer tunnels are unworkable. The locomotive has indeed beaten all rivals for ordinary railway work, not so much because of its physical advantages as a motive power, as on account of its great adaptability to various circumstances as sidings, junctions, level crossings, curves, and intermediate stations. But in a long tunnel, where none of these exist, it is by no means certain that some other power may not prove superior to the locomotive, especially when by its use several hundred horse-power would be required for ventilation.

What, then, are the means which might be employed for working long tunnels? The first question that suggests itself is, Cannot some modification be introduced so as to render locomotives applicable? Can nothing be done with the products of combustion? The steam can be condensed, the fuel can be selected free of sulphur, can nothing be done with the carbonic acid? Dr. Angus

Digitized by Google

Smith made some experiments on this subject. It was suggested to him that lime might be advantageously employed to remove the carbonic acid in mines. He therefore experimented on air tainted with carbonic acid. He removed the carbonic acid by sprays of milk of lime, and by hanging up wet cloths. He states: "A candle burnt better, and the air was rendered pleasant to breathe." He goes on to say, however, that in his opinion it is not advisable to manufacture air in this way, but that when foul it should be replaced by fresh. If the use of lime were adopted, the air from the chimney would have to be made to pass through damp lime placed on trays, or some other means taken to insure the smoke being exposed to the action of the lime immediately after it left the chimney. Each pound of lime is capable of absorbing about $\frac{3}{4}$ lb. of carbonic acid, so that about 150 lbs. would absorb all the carbonic acid given off per train mile.

Again, the substitution of liquid for solid fuel might possibly accomplish the object.[1] Many of the heavy oils contain a large proportion of hydrogen, and no doubt their use would render the atmosphere of tunnels less impure than at present; but in any case the amount of carbonic acid generated would be considerable, and the ventilation of long tunnels would still present difficulties of the gravest description. The question next arises, can any other description of locomotive be employed? The hot-water locomotive has been suggested as being suited to such work.

Engines on this principle have been working tramway cars for some years.[2] A large boiler filled with water at a high temperature, say of 374° Fahr., and the corresponding pressure of 150 lbs. per square inch above the atmosphere, gives off steam as required, the temperature and the pressure falling to say 307½° and 45 lbs. respectively. The useful work for each cubic foot of boiler is stated to be in foot lbs. 2,500 × difference of temperature in degrees Fahr. For a difference of temperature of 66½° this gives 166,500 foot lbs.; and when developed during an hour $\frac{1}{1^{\frac{1}{2}}}$ HP. per cubic foot of boiler. If this statement be correct, it is evident this class of engine is only suited for short journeys and light traffic.

Another description of locomotive has been suggested, the boiler of which has a receptacle for a mass of red-hot iron, somewhat on the plan of the tea urn. This is the invention of Mr. Robert Baillie, and the system has been tried so far as to work

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxi., p. 376; and Trans. Inst. of Naval Architects, vol. x., p. 32.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxix., p. 347.

Digitized by Google

a small donkey engine with such a boiler for some hours.[1] But this invention is less promising even than the hot-water engine. Suppose the iron be heated to 1,800° Fahr. and be allowed to cool to 400°; 1,400° would be the total amount available for heating purposes. The specific heat of iron is only about 0·12, that is to say, 1 lb. of iron in cooling 1° Fahr. will only give out heat enough to raise 1 lb. of water 0°·12. To evaporate 1 lb. of water requires as much heat as to raise the temperature 966°; that is, 1 lb. of iron to be cooled 8,000°, or nearly 6 lbs. of iron cooled 1,400°. In a journey of 30 miles, 4 tons of water might have to be evaporated, which would require 24 tons of iron to be cooled 1,400°, not including anything for waste, which would certainly amount to half the entire heat given off; the weight of the heaters for a 30-mile run would therefore be about 50 tons.

Fire-bricks require 50 per cent. more heat than iron to raise them to a given temperature, and give off 50 per cent. more in cooling; but the specific heat of all solid substances is so low, compared with that of water, that boilers with solid heaters can only be used on a very small scale.

The compressed-air engine cannot be condemned on theoretical grounds, and it would therefore seem rash to affirm that the mechanical objections cannot be got over; but the enormous difficulty of storing a sufficient quantity of compressed air with safety in a moderate compass has hitherto proved fatal to its employment on a large scale.

Having now disposed of the question of smokeless locomotives, it will be well to consider the other methods of working railways.

The first system that suggests itself is the Pneumatic. The details of this system, as applied to long tunnels, have been fully worked out by Mr. Bateman, Vice-President Inst. C.E., and M. Révy, in their proposal to lay a tube across the Channel. In this system the train carries a frame which roughly fits the inside of the tunnel. The air of the tunnel is put in motion by fans or pumps, according to the pressure required. The train is allowed to enter the tunnel, and is carried along nearly at the same speed as the air. The pressure required to produce a current of air, at the rate of 10 miles an hour, through a length of 22 miles of tube 13 feet in diameter, is given as equal to 0·825 inch of mercury, or about 9½ inches of water. For a current of 30 miles an hour, however, 7½ inches of mercury, or about 7½ feet of water, are

[1] "Railway News," 29th May, 1875.

Digitized by Google

shown to be necessary; and more than 90 per cent. of the power is employed in moving the air. In the Paper referred to, an example is given of the power required for moving a train at 30 miles an hour.

Expended in moving the air	5,674 HP.
„ „ train	587 „
Total	6,261 „

In the Author's opinion, the Pneumatic system would involve all the trouble and expense of ventilation, and would not give as great facilities for working as many other systems.

The Atmospheric system naturally suggests itself, Plate 1, Figs. 8 and 8A.

This is one of the few which held its own for a time against its powerful antagonist the locomotive. The difficulties attending the use of a tube with a valve the whole length of the railway were numerous, but were so far conquered that, in certain cases, where the traffic could be worked by shuttle trains running backwards and forwards between the termini, this system remained in use for many years.[1] The objection to the atmospheric system, that it could not adapt itself to the varied requirements of railway traffic,[2] such as branch lines, junctions, sidings, &c., would not apply in the case of a very long tunnel. The tunnel would also probably be straight, there would be no banks to disturb the tube by settlement, nor any great and sudden changes of temperature to interfere with the fitting of the valve.

The mechanical difficulties were ascertained years ago, with one exception, namely, that of dealing with a single tube of great length. In the first place, there will be a considerable amount of leakage over the whole length of the valve; and when the end of the tube near the pumps is exhausted to a partial vacuum of, say 22 inches of mercury, for each cubic foot of air that enters the tube 4 cubic feet have to be withdrawn; and thus in a very long tube the power of engine required for exhausting becomes out of all proportion to that employed in propelling the train. In the second place, a considerable time is expended after the arrival of each train in exhausting the tube for the next one. In a tunnel 20 miles long this might amount to twenty minutes or more, unless engines and pumps of enormous size were employed. It is proposed to show how both these difficulties can be overcome.

[1] It remained on the Paris and St. Germain railway from 1847 to 1860. *Vide* Minutes of Proceedings Inst. C.E., vol. xxvi., p. 345.

[2] *Vide* "Report on the Atmospheric Railway." By R. Stephenson. 4to. 1844.

Digitized by Google

The case will be assumed of a tunnel 22 miles long, with gradients of 1 in 70 rising outwards at either end. A train weighing 250 tons will on a gradient of 1 in 70 require a tractive force of

$$\text{Gravity, } \frac{250 \times 2{,}240}{70} = 8{,}000 \text{ lbs.}$$
$$\text{Friction, } 250 \times 10 = 2{,}500 \text{ ,,}$$
$$\text{Total, } 10{,}500 \text{ ,,}$$

A tube 3 feet in diameter has a sectional area of 1,018 square inches, and at a partial vacuum of 22 inches of mercury would transmit a total force of

$$1{,}018 \times 11 = 11{,}198 \text{ lbs.}$$

This, then, is the smallest tube that could be employed.

The most suitable arrangement seems to be to have a third tube between the lines of rails, in addition to the ordinary vacuum tubes. The latter are each divided into seven lengths of $3\frac{1}{7}$ miles, and every length is connected with the centre tube, the communication being closed by a valve. The centre tube is connected with air-pumps at both ends, which maintain a partial vacuum in it; as the train passes along, one length after another is opened into the centre tube by men stationed at the valves.

Suppose each length is connected with the centre tube at the time the train is at the middle of the previous length, then on the average there will constantly be one length open. The leakage[1] into this per minute will be

$$3\tfrac{1}{7} \times 186 = 585 \text{ cubic feet of air at atmospheric pressure.}$$

The area of the tube is 7 square feet, and at a velocity of 30 miles per hour the air extracted will be on the average per minute

$$2{,}640 \times 7 = 18{,}480 \text{ cubic feet at atmospheric pressure.}$$

For the level portion of the line a vacuum of 6 inches of mercury is ample, and if the central pipe be connected with air-pumps at both ends, and a vacuum of 22 inches of mercury be maintained there, it will always be possible to get more than 6 inches of vacuum in the vacuum tubes.

---

[1] *Vide* "Report on the Atmospheric Railway." By R. Stephenson. Page 6.

Digitized by Google

If there is a train on each line of rails, the total amount of air entering the centre tube per minute will be

Leakage of two tubes	1,170	cubic feet.
Haulage of two trains	36,960	„
Total .	38,130	„ at atmospheric pressure;

consequently the amount to be withdrawn at 22 inches vacuum will be

152,520 cubic feet per minute.

With a vacuum of 22 inches of mercury the average pressure on the piston of the air-pump is 6 lbs. per square inch,[1] or 864 lbs. per square foot. The total net power required is therefore

$$\frac{152{,}520 \times 864}{33{,}000} = 4{,}000 \text{ HP. nearly.}$$

If each tube were worked separately from the end there would be more leakage, but there would be a saving in power, from the fact that great part of the air would be withdrawn at or near the atmospheric pressure; but then, after a train had passed through, time would be wasted in exhausting the tube, whereas by this system there is practically no limit, except in the power employed, to the frequency of trains; and although 30 miles an hour has been taken in this example, the speed might be greatly increased. The lengths and gradients stated above are approximately those of the Channel tunnel. In the case of that tunnel, if there were any objection to the use of a central tube, there is another means of breaking up the vacuum tubes into convenient lengths. There is an inexhaustible source of power in the sea above. The water could be introduced without danger, and employed to work turbines at any point in the tunnel. The water would of course have to be lifted again by pumps, but as both turbines and pumps work economically, the actual work got out of the turbines would probably amount to 40 or 50 per cent. of the power used in pumping.

There is yet one other method of working long tunnels, and that is by means of ropes.

The longest rope that has ever been used for a similar purpose, as far as the Author is aware, was that on the Blackwall railway, which was 3¼ miles long. Experiments, to determine the friction

[1] *Vide* "Report on the Atmospheric Railway." By R. Stephenson.

Digitized by Google

of the rope and drum,[1] showed that the power required to overcome friction was about 1½ cwt. per ton. Mr. R. Stephenson gives the friction of a rope on the Euston incline, the weight of which was 7 tons, as 7½ cwt.;[2] and it is generally considered that the friction of such ropes amounts to one-twentieth of their weight.[3]

These statements tend to the conclusion that it would be difficult, if not impossible, to work a long tunnel by ropes; but, by keeping the sheaves in good order, and taking general precautions, the friction could assuredly be much reduced.

The best plan appears to be to have an endless rope kept constantly running by engines at both ends of the tunnel. The difficulty in attaching a train to a rope running at, say, 30 miles an hour could be got over by clipping the rope between a pair of wheels, which, at first allowed to revolve, are gradually stopped by putting on pressure. The train would ultimately acquire the same velocity as the rope, without any undue strain or severe shock. If this can be accomplished, the rope seems to be the most feasible method of working long tunnels. One great advantage is that the permanent way will be exactly the same as for an ordinary locomotive line, and in case of an accident, locomotives could at any time be employed. The power required to work a rope will, of course, depend upon the friction. A steel wire rope, weighing 10 lbs. per yard, or 8 tons per mile, could be worked with safety up to a strain of 11 tons. If the friction could be kept down to ¾ cwt. per ton, then for 22 miles it would be about 6½ tons; leaving 4½ tons available for working the trains. This is sufficient to pull a train of 250 tons up an incline of 1 in 70. There might, therefore, be constantly one train on each line of rails. At a speed of 30 miles per hour this requires at each end of the tunnel an effective horse-power of

$$\frac{11 \times 2{,}240 \times 2{,}640}{33{,}000} = 2{,}000;$$

and for both ends of the tunnel, 4,000 HP.; or exactly the same as in the case of the atmospheric system.

Even where the locomotive is not employed in tunnels of extreme length, it is clear that some means must be taken to insure a slight draught so as to keep the air from getting stagnant.

---

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. v., p. 153.
[2] *Vide* "Report on the Atmospheric Railway." By R. Stephenson. Page 23.
[3] *Vide* Minutes of Proceedings Inst. C.E., vol. xv., p. 360.

Digitized by Google

The amount of air allowed per man in some collieries is 600 cubic feet per minute, but that is for the purpose of taking away the large quantity of noxious gas given off by the sides of the pit, and the number of men is only stated as a rough indication of the size of the workings. The best information on this subject is in a paper by Mr. André,[1] who has tried to separate the amounts of air required for the several purposes. In his opinion, 3 cubic feet of air per minute are absolutely necessary for a man and his candle, and at least three times this amount, or 9 cubic feet, should be supplied. With double this allowance, or say 1,000 cubic feet per hour—and supposing there are constantly 1,000 people in the tunnel—the air required for ventilation will be only 1,000,000 cubic feet per hour, equivalent to a current of about ½ mile per hour.

In the case of long tunnels, the proper plan appears to the Author to be to erect ventilating machinery capable of inducing a current of 10 miles per hour; to use this machinery for ventilation while working with locomotives until the traffic becomes so great that the ventilation is imperfect; then to introduce the rope and reduce the ventilating current to 2 or 3 miles per hour, employing the engines for hauling instead of ventilating. In case of any accident short of a complete break-down of all the engines at one end, the fans could all be set going and the tunnel worked by ordinary locomotives till the damage was repaired. In the case of a tunnel 22 miles long six trains a day could be worked each way through perfectly clear air, or twelve trains a day each way through air rather worse than the worst air on the Metropolitan railway, but not likely to injure a healthy person.

A summary has already been given (page 41) of the Author's conclusions as to tunnels up to 7 miles in length; it only remains briefly to recapitulate what has been said with regard to longer tunnels.

1st. When long tunnels without shafts have to be ventilated, a current of air should be caused to pass through by means of a fan placed near one end, that end being closed by doors.

2nd. For a given amount of traffic the power required to ventilate long tunnels varies as the fourth power of the length.

3rd. When a long tunnel has to be ventilated, it is more advantageous to have a double-line tunnel, than two single-line tunnels.

4th. For a tunnel of given length there is a limit to the traffic that can be carried by locomotives, beyond which ventilation

[1] *Vide* Society of Engineers' Transactions, 1874, p. 23.

Digitized by Google

becomes impossible; and when this limit has been reached some other tractive power must be employed.

This limit cannot be definitely fixed, but for a tunnel 22 miles in length it does not exceed a total of twenty trains per day.

Artificial ventilation can be easily applied to tunnels of moderate length. For long tunnels, however, the Author has endeavoured to show that there are difficulties, and that in extreme cases these can be best overcome, not by polluting the air with smoke and then extracting it, but by employing some means of traction which will not interfere with the purity of the air.

The communication is accompanied by a series of diagrams, from which Plate 1 has been compiled.

Digitized by Google

Mr. V. G. Bell said Mr. Morrison, who had gone to China to construct the first railway authorised in that country, had asked him to take charge of this Paper. It would not be disputed that the proportion of carbonic acid in the air was the best test of its quality; but there were great differences of opinion as to the proportion which was allowable. At the same time he thought that if it was sought to ventilate by artificial means a railway tunnel in which the passengers, not all in robust health, were to pass any appreciable time, a high state of purity ought to be aimed at, instead of seeking the limit of impurity to which healthy persons might be subjected. Mr. Morrison had shown that there was a limit to the length of tunnel which could be successfully ventilated with ordinary locomotive engines, if the plan of driving a current of air through the tunnel were employed; but many persons (of whom he was one) would demur to the opinion that the locomotive must be abandoned. Mr. Morrison had not alluded to the many new expedients adopted on the Metropolitan railway. He hoped the Engineers of that company would explain them, and state the results obtained. The Author had not proved that the locomotive must be superseded. It had been shown, with reference to the proposed Channel Tunnel, that the pneumatic method would require 6,000 HP. for each train of 250 tons; and that either the atmospheric or the rope system would require 2,000 HP., or about 3,000 actual indicated HP. A locomotive to do the same work would only require to develop about one-tenth part of that power. The cost of traction with the atmospheric or the rope system would be £50,000 a year, which capitalised at 5 per cent. represented £1,000,000. The first cost of laying down the system could not be much short of £350,000. The work might be done with three locomotives at a cost of £3,000 each. Adding the extra cost of maintenance capitalised, there would be a sum of a million and a half sterling in favour of working with locomotives. Mr. Morrison had alluded to the compressed-air locomotive, but merely stated that there were serious mechanical difficulties in the way of its adoption. But compressed air appeared to be so convenient, and to meet the requirements of the case so thoroughly, that it might not be unprofitable to provoke a discussion on the subject. A train starting from one end of the Channel Tunnel would, if allowed to run down the gradient of 1 in 80, attain a maximum speed of 80 miles an hour; that would bring it to within 3 miles of the centre of the tunnel, leaving $3\frac{1}{4}$ miles of an up gradient of 1 in 2,640, $8\frac{1}{4}$ miles of a down gradient of 1 in 2,640, and $3\frac{1}{2}$ miles of an up gradient of 1 in 70. So that there would be

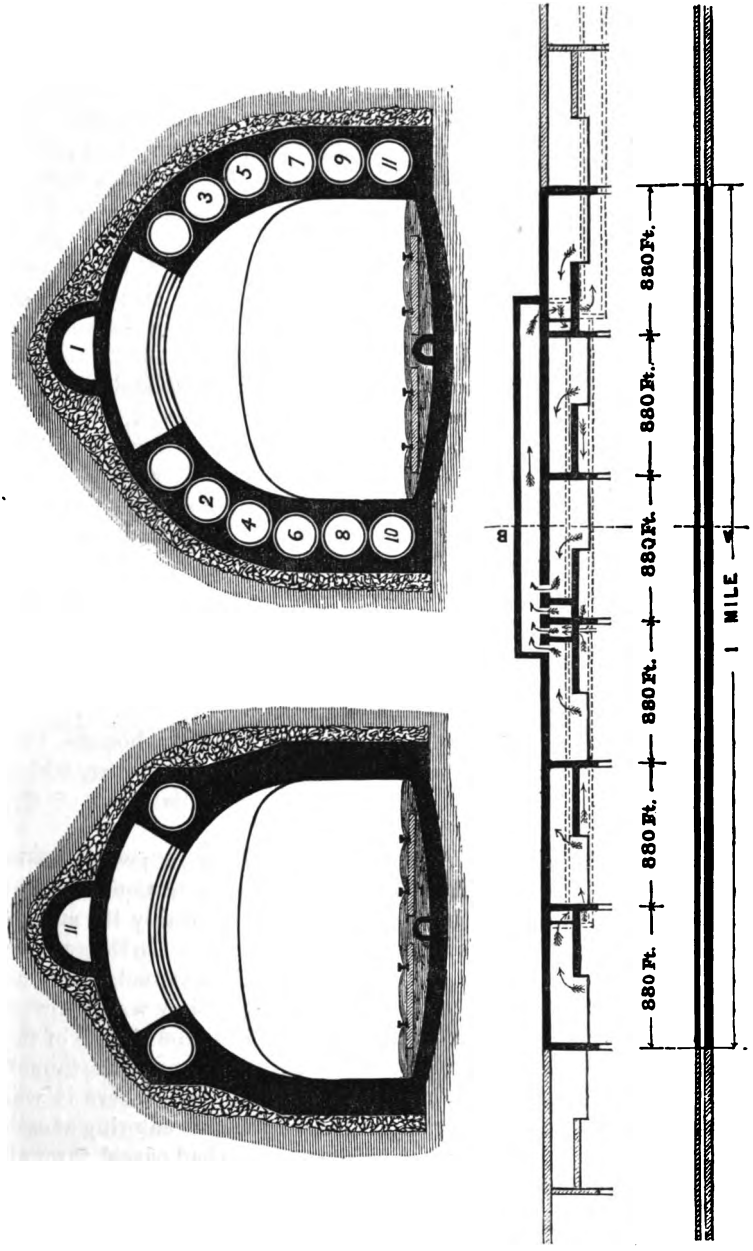
Digitized by Google

in all 15 miles on which to maintain the speed of 30 miles an hour, the average tractive resistance being about 16½ lbs. per ton. He would suppose the case of an engine with the most perfect valve gear, with an automatic variable cut-off to suit the constant decrease of pressure in the air vessel, starting with a cut-off of $\frac{1}{20}$ lb. As there could not be less than ½ atmosphere above atmospheric pressure at the end of the stroke, this would give an initial pressure of 30 atmospheres in the cylinder. It was possible indeed to compress air to that extent. There was plenty of water in the English Channel to keep down the temperature in the compressors, and it would not be impracticable to maintain the temperature in the cylinders of the locomotive if they were jacketed, and if a store of water at high temperature were taken for the purpose. He therefore gave credit for the full theoretical effect of the expansion of the air. The mean pressure in the cylinders would then be 6 atmospheres. The ratio of expansion would be 15; and the cubic contents of an air vessel necessary to take a train of 250 tons weight 15 miles would be 2,747 feet. A cylinder of 6 feet diameter, the largest that could be safely put on driving-wheels on an ordinary gauge, would require to be 93 feet long to contain that quantity of air, and to stand a pressure of 426 lbs. to the square inch, the metal could not be much less than 1¾ inch. The cylinder would weigh about 64 tons, and the entire locomotive would not weigh less than 100 tons, or two-fifths of the gross weight of the train, or two-thirds of the net weight. It appeared therefore that the compressed-air locomotive was only suited for light traffic and short distances. The horse-power developed by the locomotive would be 330, but to compress the same amount of air in the same space of time would require 1,215 HP.; in addition to which there was the loss of power represented by the heat which was lost, and which he had supposed to be replaced artificially. To maintain the temperature of 60° in the cylinder required 446,040 units of heat, equal to 27 cwt. of water cooled down 150°; but as only half the surfaces could be utilised, and a certain margin was required, he reckoned that 3 tons at 212° would be needed. To raise the temperature of that quantity of water from 60° to 212° would require the combustion of 102 lbs. of coal, which would represent about 85 HP. for half an hour. Consequently the total power was 1,300 HP. An ordinary locomotive in doing the same amount of useful work would develop only 238 HP. An ordinary locomotive, then, appeared to have such a great advantage over its rivals that it could not be discarded until ingenuity had been exercised in trying to ventilate the tunnel.

Digitized by Google

One great reason for the apparent difficulty of ventilating long tunnels without shafts had been their comparison with mines, though the conditions were quite dissimilar. They ought rather to compare a long tunnel without shafts to a long tunnel with shafts, or to a short tunnel without shafts. There it was seen that the tunnel ventilated itself, because the heated gases of the locomotive issuing in mixture with the steam or watery vapour ascended rapidly out of the tunnel through the shafts or at the ends, and did not deteriorate the air in the lower part. He would therefore propose, for those tunnels where vertical shafts could not be provided at sufficiently close intervals, that air-ways should be constructed along the line of the tunnel itself from points at stated intervals in the roof to the nearest shaft or to the mouth of the tunnel. They should be kept separate, and at the outlet of each a fan should be employed to induce the required draught from the interior of the tunnel. Figs. 1, page 53, would illustrate the principle of this suggestion. Two cross sections were represented, one near the shaft and the other near the centre, and a longitudinal section of 1 mile length of the Channel Tunnel. He proposed to construct air-ways having a sectional area of 10 square feet each from the centre of each mile length to the nearest shaft. There would be, therefore, eleven leading to one shaft and eleven to the other. At the outlet of each a fan of proper dimensions was to be employed. The main air-ways were not to open direct into the tunnel at the centre of the mile length, but subsidiary air-ways were to branch off from that point to various points in the length of the tunnel. He had shown the mile divided into six sections. It was proposed to separate the sections by vertical screens reaching down to near the level of the top of the engine chimney. This was in order to prevent the currents towards the different air-ways interfering with each other, and also in order that the gases might not be carried about and cooled down by the current of cold air in the lower part of the tunnel. He had also shown a large chamber above the roof of the tunnel for half the length of each section. This should have a cross section of about 40 square feet. Supposing trains to run at intervals of half an hour in each direction, the gases would have to be withdrawn in a quarter of an hour. The greatest distance being 440 feet, a current of 30 feet per minute would be required in the chamber. There being six sections, and the air-way having a cross section of 10 square feet, the current required in the main air-ways would be therefore 720 feet per minute. Consequently there would be withdrawn 7,200 cubic feet

Digitized by Google



FIGS 1.

Digitized by Google

per minute from each mile length of tunnel; in other words, in addition to the steam and gases, a quantity of atmospheric air equal to nine times their bulk. To replace that air the current inwards along the lower part of the tunnel would vary from about 200 feet per minute at the shafts to zero at the centre. To produce that varying current in the tunnel a vacuum of $\frac{1}{100}$ inch of water would be required in the chambers in the section nearest the shaft, decreasing in the other sections down to $\frac{1}{5000}$ inch in the centre sections. To overcome friction there would be required in the subsidiary air-ways a vacuum of $\frac{1}{10}$ inch of water, and in the main air-ways a vacuum of 1·35 inch for every mile of their lengths. Thus for the first mile length the required vacuum would be 0·8 inch, and for the eleventh mile 14·27 inches. The sum of all the vacuums at each shaft was 83 inches. The net horse-power to produce these and to extract 7,200 cubic feet of air from each mile would be nearly 100; and the indicated horse-power of the engines would therefore require to be about 200. He did not say that the diagrams showed the best arrangement that could be made, but they illustrated the principle for which he contended. With respect to the cost, taking the extra excavation required in the construction of the tunnel, 22 miles long, at 10*s.* per cubic yard, the extra brickwork at £3, and the dry filling at £1, the total excess of expenditure for the fabric of the tunnel would be £518,980. A sum of £50,000 would suffice for the engines, fans, and buildings, and £10,000 for the air passages from the ends of the tunnel to the fan-house. The maintenance and working would cost about £5,000 a year, which represented a capital of £100,000. Thus the total cost of the system was under £700,000.

Dr. Pole thought the Author had not been in possession of all the facts of the case when he described the Mont Cenis Tunnel as being ventilated only by natural means. Probably the system had been changed since his information was obtained. In the autumn of 1873 he was at Modane, at the north end of the tunnel, where he saw a large establishment of air-exhausters worked by water-power, the object of which was to extract the air from the middle of the tunnel. There was, he was told, a channel at the bottom of the tunnel, conveying the air from the middle to the north end, where it was sucked out by the exhausting apparatus, the fresh air entering at each end to supply its place. All the passengers who had passed through the tunnel testified to the efficiency of the ventilation, as they found nothing at all unpleasant in the state of the atmosphere. Dr. Pole had, at the time of his visit, no means of obtaining information

Digitized by Google

beyond what he gained in conversation with the workmen engaged about the place; but he thought, as this was an actual example of effective artificial tunnel ventilation on a large scale, it would be highly desirable to obtain full and accurate information respecting it.

Mr. JOHN DIXON doubted the accuracy of some of the Author's calculations. If the Channel Tunnel were once pierced the difficulties in the way of ventilation would soon be overcome, as similar difficulties had been in reference to other undertakings which had been regarded as impracticable. He believed that the Mont Cenis Tunnel had been badly ventilated when the system of fans, &c., was in use; but at present it ventilated itself, and that most effectually. It would be remembered that the same thing had occurred in reference to the Metropolitan railway, which now practically ventilated itself.

Mr. D. P. MORISON said he thought that a few facts collected in some of the large coal mines in the North of England might be acceptable. There were pits, ventilated by furnace and by mechanical means, in which the air-ways were 11 miles long, and they were kept perfectly clear in spite of the gases constantly evolved. He therefore saw no difficulty in drawing off from a tunnel, of whatever length, if sufficient power were applied, the products of combustion from locomotives or of human respiration. He thought the Author had made a slight mistake in his figures with regard to the power and amount of air required to ventilate tunnels. The horse-power required to ventilate the longest tunnel on the Metropolitan railway would not exceed 94, as would be seen from the following figures:—Let the amount of air required be 400,000 cubic feet per minute, and suppose the length to be 1 mile, and the area of the tunnel to be 418 square feet. Then the water gauge, or head required, would be, by the formula, $\frac{P D V^2}{A} \cdot 0008$,

where
P = Perimeter in mètres,
D = Length ,,
V^2 = Velocity in cubic mètres per second, squared,
A = Area in square mètres,

26½ millimètres, or about 1·04 inch. In order to allow for extra friction in the ventilating shafts or approaches, call this 1¼ inch; the HP. utilised would be then

$$\frac{400{,}000 \times 1{\cdot}5 \times 5{\cdot}2}{33{,}000} 94{\cdot}6,$$

or say 180 HP. indicated on the engine. That calculation was based upon the assumption that 400,000 cubic feet of fresh air would be required every minute, but he believed that in reality less

Digitized by Google

than one-half would be sufficient. To set in circulation the same amount of air through the Mont Cenis Tunnel would require about 1,100 HP.; and for the Channel Tunnel, with twenty trains a day, about 4,000 HP. would be needed. A water guage, or a depression of 7 inches, would require to be produced at one end, and a corresponding pressure at the opposite end, making a total water gauge of 14 inches. Both in this country and abroad the ventilation of mines had, by mechanical means, been so far improved that he felt sure that, with the assistance of engineers, no difficulty would be experienced in solving the question. He looked upon ventilation as simple compared with the work of piercing the tunnels themselves. He might add that in the Cannock Chase district, a colliery ventilated by a Guibal ventilator had, passing through air-ways of much less sectional area than the tunnels named, a current of 303,000 cubic feet per minute at 3·2 inches water gauge.

Mr. H. B. Wilson said, having been present at the opening of the Metropolitan railway in 1864, he proposed on his return to New York, where he resided, a somewhat similar line for that city; and a company was formed to carry it out. The ventilation was to be accomplished by means of cast-iron pillars 18 inches in diameter, and 50 feet apart, connecting with the tunnel alternately, at the bottom and the top, through which both the heavier and the lighter gases would be ejected and the fresh air be drawn in, by the action of the trains. The pillars might be made to represent Doric columns surmounted with gas lamps, and having an ornamental appearance. The line, however, owing to certain difficulties that had been interposed, had not been carried out. It had been estimated that when the trains ran at intervals of five minutes, the air of the entire tunnel would be changed every hour. He suggested that this method of ventilation might be adopted in a modified form on the Metropolitan railway, where the air was very offensive.

Dr. Letheby remarked that the Paper dealt with a very important subject, a little theoretically perhaps, but yet exhaustively. The question was not only important in an engineering, but also in a sanitary point of view; and as he had undertaken inquiries with regard to the quality of the atmosphere in railway tunnels, he would venture to make a few observations on the subject. He did not think the Author was quite correct in regard to the extent to which each individual in a tunnel vitiated the atmosphere. Instead of its being in the proportion of five hundred persons to a pound of the combustible used per mile, it should be one thousand

Digitized by Google

five hundred persons. Experiments dating from the time of Sir Humphry Davy had established beyond question the precise quantity of carbonic acid produced by each individual when at rest. Each person consumed about 2¼ grains of carbon per minute, equal to 8·25 grains, or rather more than 17 cubic inches, of carbonic acid, and, with the hydrogen consumed in his body, it amounted to about 20 cubic inches of atmospheric oxygen consumed in a minute. Dividing the 7,000 grains making a pound of the combustible by 4½ grains, the amount consumed by each person in the run of 1 mile at the speed of 30 miles an hour, it would be seen that there were one thousand five hundred and fifty persons (instead of five hundred) to every pound of carbon. That was an important consideration in regard to the extent to which each individual vitiated the atmosphere, for it showed that the vitiating effect of respiration was insignificant. With reference to other vitiating agents, carbonic oxide was one of the most deadly. One per cent. of it in the atmosphere of a tunnel would kill every person in it in ten minutes: hence the great importance of a perfect combustion of carbon. As to carbonic acid, the proportion found in the breath was about 4½ per cent., but this was irrespirable; even 2 per cent. of carbonic acid in the atmosphere was exceedingly distressing. In some dormitories examined by Dr. Bence Jones, where the "casuals" were in a very uncomfortable state, the percentage of carbonic acid was only 1¼. In others in England and France, where there were from 58 to 80 volumes of carbonic acid in 100,000 of air, the inmates did not appear to suffer much; and the same was the case with some of the crowded lodging-houses of the city, where he had found as much as 100 volumes in 10,000 of air: so also in certain mills and workshops with from 28 to 30 volumes of carbonic acid in 10,000 of air. Now, Mr. Morrison's calculations were based upon the supposition that there ought not to be more than 8½ volumes of carbonic acid in 10,000 of air, but that, he believed, was an unnecessarily narrow limit, for people often breathed for many hours an atmosphere with much larger proportions of carbonic acid; the atmosphere of the Court of Chancery, for example, had contained 19·8 volumes of carbonic acid in 10,000 of air; that of the Chamber of Deputies in Paris, 25 in 10,000; the London theatres, 10·2 in 10,000; and those of Paris from 23 to 43 per 10,000. He thought, therefore, that instead of taking 8½, the Author might have safely taken 15 as his basis. Not that he would recommend any one to live constantly in such an atmosphere, but he did not know that it would do any harm for a reasonable time. He looked upon 10 in

Digitized by Google

10,000 as the point where the atmosphere was getting bad; but there were many instances in which persons lived, apparently without discomfort, in an atmosphere containing considerably more than 15 volumes of carbonic acid in 10,000 of air. If a tunnel could be traversed in an hour or two hours, he thought the atmosphere might safely contain 15 volumes to 10,000; and taking that as a basis, the calculation as to the amount of air required to displace that which was vitiated and consumed would be considerably altered. A great deal of the carbonic acid gas in the Metropolitan railway (which at no part exceeded 16 in 10,000) was got rid of by diffusion through the walls, one of the most important methods by which it could be removed. It was difficult to believe, without actual experiment, how large a quantity of carbonic acid would pass through a wet, porous substance. There was, therefore, he thought, no great cause for alarm with regard to the future of tunnels: for supposing that a normal atmosphere contained 4 volumes of carbonic acid in 10,000 of air, and that 15 volumes of carbonic acid might be permitted to exist in it, then if 35 lbs. of pure carbon were consumed per mile in a tunnel there would be produced 1,097 cubic feet of carbonic acid gas, which, with the oxygen consumed, would require not 2,204,000 cubic feet of fresh air, as the Author supposed, but only 1,002,757 cubic feet; amounting, with a sectional area of 473 square feet, to 2,120 feet of tunnel, or about $\frac{4}{10}$ mile. So that supposing the tunnel to be impervious, not allowing the diffusion of gases through the walls, if it were ventilated once for every two trains, that would be a good and effective ventilation. But suppose the ventilation could not be effected, the question would then arise whether some other fuel, less vitiating in its action, could not be used. Twenty-seven pounds of benzole, doing the work of 35 lbs. of pure carbon, or of 37·9 lbs. of coke containing 92·4 per cent. of carbon, would consume 980 cubic feet of oxygen, and produce 786 feet of carbonic acid, and it would vitiate only 719,445 feet of air; 27·7 lbs. of the common oils, doing the same work, would consume 1,072 cubic feet of oxygen, and produce 673 cubic feet of carbonic acid, vitiating 617,178 cubic feet of air. The fuel that vitiated the atmosphere to the least extent was wood spirit; but it was unfortunate that, in descending in the scale of vitiation, compounds were reached that were richer and richer in hydrogen, and therefore more and more volatile, though they might be used in the form of spray from a jet. In the case of paraffin oil, it took 23 lbs. to do the work of 35 lbs. of pure carbon, the oil consuming only 932 cubic feet of oxygen, producing 621 cubic feet of carbonic acid, and

Digitized by Google

vitiating 569,202 cubic feet of air. But was it possible, by any contrivance, to use hydrogen? No carbonic acid would then be generated; there would simply be an abstraction of oxygen. He had made experiments on birds, to ascertain how far he could go in the absorption of the oxygen of the atmosphere, taking care to remove the carbonic acid as fast as it was produced; and he found that he could bring down the proportion of oxygen to less than one-half without the bird showing any sign of distress. Now 11·6 lbs. of hydrogen would do the work of 35 lbs. of pure carbon. It amounted to nearly 2,190 cubic feet; and if that could be carried, it would consume only 1,092 cubic feet of oxygen, producing no carbonic acid, and it would only destroy 5,460 cubic feet of air. The hydrogen might be so used that the whole theoretical quantity of heat (twice as much as the practical quantity) might be utilised; and, considering how much was lost by the carbon, he was not sure whether 5½ lbs. of hydrogen, instead of over 11 lbs., would not do the work of the 35 lbs. of carbon. Then another question arose, whether, if the fuel could not be altered, anything could be used to absorb the carbonic acid as fast as it was produced? Twenty-eight pounds of lime would absorb 22 lbs. of carbonic acid, the product of 6 lbs. of carbon. He did not think there would be much practical difficulty in the use of lime in a tunnel, if, instead of the engine discharging the steam and the products of combustion together, the products of combustion were made to pass through lime purifiers; and in that way the whole of the carbonic acid would be absorbed. There was also the question whether some other liquid could be used, the latent heat of which was considerably less than that of water. Both mercurial and chloroform engines had, he believed, been used successfully as a matter of experiment, care being taken to retain the whole of the vapour. The only disadvantage arising from the mercurial engine was that it salivated all the rats on board the boats. Again, liquid carbonic acid possessed an extraordinary expansive power, it being about four times as great as that of the atmosphere, and was, therefore, a powerful motive agent. But after all, could not the atmosphere be carried with the passengers? Less than 4 cubic feet of air per passenger were actually consumed, so far as the oxygen was concerned, per hour, though about 11 feet were breathed and vitiated: surely this amount could easily be carried with the passengers themselves; the only difficulty would be to educate them in using it.

Mr. T. Sopwith, junior, said it had been stated that long tunnels somehow ventilated themselves. As, however, there was no

Digitized by Google

experience of tunnels 22 miles long, it might be well to consider what were the natural means of ventilation in such a case. The three means of natural ventilation which suggested themselves were—1st, the difference of atmospheric pressure which might exist between the two ends of the tunnel; 2nd, the force and direction of the wind; and 3rd, the displacement of air caused by the passage of each train through the tunnel. With regard to the first, a difference of pressure indicated by 0·06 inch of mercury was by no means unusual at points 50 miles apart. Taking 0·003 inch for 22 miles, there would be a pressure equal to 0·35 inch of water, giving $\frac{1}{3}$ inch water gauge. Such a pressure in a tunnel 22 miles long would give a mean velocity of air of $1\frac{1}{3}$ mile an hour, and it would take sixteen hours for pure air to pass from one end of the tunnel to the other. The highest variation of atmospheric pressure registered in the Meteorological Office had been 0·66 inch of mercury over a distance of 60 miles, equal to $\frac{1}{4}$ inch for a distance of 22 miles, or 3 inches water-gauge; even this remarkable variation of pressure would only give a velocity of air of $6\frac{1}{2}$ miles an hour, and pure air would require three hours and a half to travel from one end to the other. If, therefore, the effect of the variation of pressure were constant, which it was not, it would not produce a sufficient current of air to afford good ventilation. The force and direction of the wind was nearly allied to the preceding. In tunnels over 1 mile or 2 miles in length it would probably have no effect. The amount of air displaced would diminish in proportion as the length of the tunnel increased—he was not prepared to say in what proportion. Judging from some statements in the Paper, it might decrease in proportion to the length of the tunnel raised to the fourth power. If a train entered a long tunnel at a rate of 30 miles an hour, the air was heaped up in front of the train, until it attained such a pressure that it had to seek relief either by escaping behind the train, or by allowing itself to be forced along the whole length of the tunnel. He could not imagine that a column of air so long as 10 or 12 miles could at any time be forced along at a rapid rate; and he was disposed to think that any effects of ventilation from that cause would not be attained until the train was within 2 or 3 miles of its exit, when the diminished quantity of air in front could be readily moved by the impetus of the train. Whether the tunnel were partitioned or not did not materially affect what he had stated; but he did not agree with the opinion of the Author, that there was no advantage in introducing a longitudinal vertical partition in a long tunnel. Though

Digitized by Google

the effect of each train passing through was but slight, it would be accumulative; and if the trains succeeded each other every hour, each train would reap some advantage from its predecessor, and thus a current of considerable velocity might eventually be obtained if the tunnel were partitioned. It would not, however, be obtained if the conflicting draughts were to meet in one large undivided tunnel, the trains running in opposite directions. The chief difficulty apprehended by the Author was the removal of the carbonic acid gas generated by the locomotive at the rate of 1,100 cubic feet per minute, with an assumed consumption of 35 lbs. of carbon per train mile. The Author assumed ordinary air to contain 3½ parts of carbonic acid gas in 10,000; and he took 8½ parts in 10,000 as the limit of vitiation which it was not desirable to pass. He further stated that in a tunnel 22 miles long, with forty trains a day, 14,500 effective HP. would be required to keep the air at that standard of purity. The statement was somewhat startling and invited attention: 35 lbs. of carbon per train seemed an ample allowance, and he did not think it would be reached if the driver entered the tunnel with a maximum pressure of steam, and left it at a minimum pressure. The atmosphere of a long tunnel (and this would be especially the case under the Channel) was saturated with moisture. Aqueous vapour escaping from the locomotive would surcharge the atmosphere, and the condensation would be rapid. It would, he believed, combine more readily with gases than with mixed air, or than it would with common air, which was a mixture of gases; and the tendency of the aqueous vapour would be to take up a considerable portion of carbonic acid and sulphurous gas, to bring it down when it assumed the form of water, and there would then be a natural drainage by the means provided in the tunnel. In estimating 35 lbs. of carbon per train mile, did the Author consider that as the amount of coke loaded into the fire-box, or had he made any allowance for the ash left, for such unconsumed portions of carbon as escaped through the fire-box, and for the soot (more considerable than might appear at first sight even with the consumption of coke) escaping through the chimney? If not, for these he believed some reduction might be made. The subject introduced by the Author was a new one, and he regretted that he could not enter more circumstantially into particulars; but he thought that the influences he had indicated would show a considerable decrease in the assumed quantity of 1,100 feet of carbon per train mile. He could not agree with the Author in fixing 8½ parts of carbonic acid in 10,000 as the utmost limit of vitiation to be allowed in so

Digitized by Google

exceptional a case as passing through a tunnel 22 miles long, especially if he accepted the figures of Dr. Angus Smith that had been cited as to the amount of carbonic acid gas found in air which was known to be quite endurable in other circumstances: 8½ parts in 10,000 probably represented a purer air than they were then breathing. In the pits of London theatres there were 32 parts in 10,000, and if such air were divested of heat and organic impurities it would be far from disagreeable. Dr. Angus Smith stated that the mean of three hundred and thirty-nine experiments in the mines of Cornwall gave 78 parts in 10,000; yet the air was sufficiently pure to enable the men to work eight or nine hours a day; and if so, railway passengers might, he thought, endure a similar vitiation for so short a time as would be required to traverse a tunnel 22 miles long. It was obvious that if the ventilation could be divided into sections the enormous amount of horse-power calculated by the Author might be much diminished. To illustrate this view the diagram of the proposed Channel Tunnel (Plate 1, Fig. 9) was very appropriate. A train going from England to France would enter at "A" with a full fire-box and a maximum pressure as far as "C." Between those points there would be no appreciable consumption of carbon, nor probably until the train nearly approached "D" need the consumption be anything like 35 lbs. At first the generation of carbonic acid would be next to nothing, and from "D" to "E" it would probably be at the rate of not more than one-third of what the Author had stated, say 300 feet per minute. From "E" to "G," in mounting a gradient, the consumption might be more than 35 lbs. But the question no longer related, under the special circumstances of the section, to a long tunnel, when the difficulties of ventilation had been shown to increase as its length raised to the fourth power, but to a tunnel only 4 or 5 miles long. It might be said that long tunnels were more likely to be made through hills than under valleys; but a tunnel, wherever it might be, could be put into much the same conditions for ventilation by dividing it into several sections. This might easily be done by making the tunnel of an additional height, bratticing horizontally in one portion of its length, and using one tunnel for the indraft at one side, and the other for the outdraft. Taking the Author's own figures, it would be found that, saving some allowance which ought to be made for friction, sixty-four times the power would be required in a tunnel 20 miles long, ventilated in its whole length in one section, as compared with the same tunnel divided into four sections, each of which had its own independent ventilation. He was inclined

Digitized by Google

to think that a ventilating power of 200 or 300 HP. at each end would be ample for a tunnel even 22 miles long, and he believed that the traffic might be conducted with locomotives without the necessity of going back to the atmospheric system, or to the system of traction by wire ropes. While differing materially from some of the conclusions at which the Author had arrived, he believed that the laws he had laid down ought to enter into the consideration of any one who proposed to make a long tunnel.

Mr. ANDRÉ said two opinions had been expressed with reference to the ventilation of a long tunnel like that proposed to be taken under the Channel. One was that the difficulty was insuperable, or at least very great, and the other that there was no difficulty at all, and that the ventilation might be left pretty much to take care of itself. His own belief was that the difficulty was not insuperable, but that it was one of considerable magnitude. Having had considerable experience in the ventilation of underground workings, he might be permitted to make some remarks on the subject. With regard to the foul gases produced by combustion, he thought the Author had overestimated the importance of carbonic acid, and underestimated some of the other products. It was unreasonable to look for absolute purity in the atmosphere of a tunnel. If persons constantly breathed such atmospheres as were found in churches, chapels, theatres, concert-rooms, ball-rooms, and even in sitting-rooms, pretty highly charged with carbonic acid gas, without inconvenience or injury, they ought to be content with something like the same atmosphere for a very short time in a tunnel. Little was to be feared from the presence of even 15 parts in 10,000, especially since carbonic acid gas was quickly diffused through the sides and the floor of a tunnel. That, of course, would make a great difference in the amount of air required to be passed through the tunnel in order to render the atmosphere pure. He had always found in the upcast shaft of a mine ventilated by a furnace, that there was a notable proportion of carbonic oxide, and he had also found it in the air of ordinary chimneys. Having regard to its very deadly character, the Author, he thought, had not given that product sufficient consideration. He also stated that sulphur was not injurious; but it certainly was very unpleasant, and passengers greatly objected to it. He thought all that was required might be accomplished by natural ventilation. The Author stated that cold air entered at the bottom of the tunnel, and heated air passed out at the top. That, however, was only the case when the atmosphere was in a state of perfect calm. In such a case the

Digitized by Google

cold air entered at each end, the heated air passed out at the top, and in the middle there was a kind of neutral stratum which was not much interfered with by the currents. When the wind was blowing the ventilation took place in quite a different manner. In the case of a tunnel running due north and south, when the wind was blowing from any of the southern points the ventilation would be from the southern to the northern end; the whole of the pure air would enter at one end, and the foul air would pass out at the other. If the wind was blowing from the north, the state of things would be reversed. If the wind was blowing due east or west the direction of the current would depend upon the approaches to the tunnel, one of which would be sure to catch the wind more than the other. That ought to be taken into account in any system of ventilation, because the artificial ventilation should be made to assist as far as possible the natural ventilation. As the heated air passed upwards and skimmed along the top of the tunnel, it might be got rid of in various ways. By means of a horizontal chimney along the top, with longitudinal openings at frequent intervals, the heated gases might escape, especially carbonic oxide, on account of its specific gravity. The greater portion of the gases would, he thought, pass into the chimney, and the remainder might be taken up by the moisture in the tunnel. There might be a stream of water flowing in an open trough, or lime, or other things, if necessary, might be used to get rid of the carbonic acid, but he did not think there would be much difficulty in enabling it to pass off of itself. With a tunnel constructed in that manner sufficient natural ventilation might be obtained. The current would be slow, but adequate. The atmosphere in the carriages would be pure enough for the passengers to breathe without inconvenience. If, however, that were not the case, the ventilation might be assisted by a fan at each end, which ought to work according to the direction of the wind. But if that were found insufficient, the plan alluded to by Dr. Letheby, of ventilating the carriages themselves, might be adopted. A reservoir of air, not necessarily a large one, could be carried, and might be distributed by means of pipes, and let out again through openings. If each passenger breathed only 2 cubic feet per hour, as he understood Dr. Letheby to say, he would be breathing the same air over ten times, and he thought there must be some mistake in Dr. Letheby's statement. A person at rest breathed about 500 cubic inches a minute, or $\frac{1}{3}$ cubic foot; but in a railway carriage it was necessary to take into account the heating of the air by the bodies of the passengers, and double the amount therefore

Digitized by Google

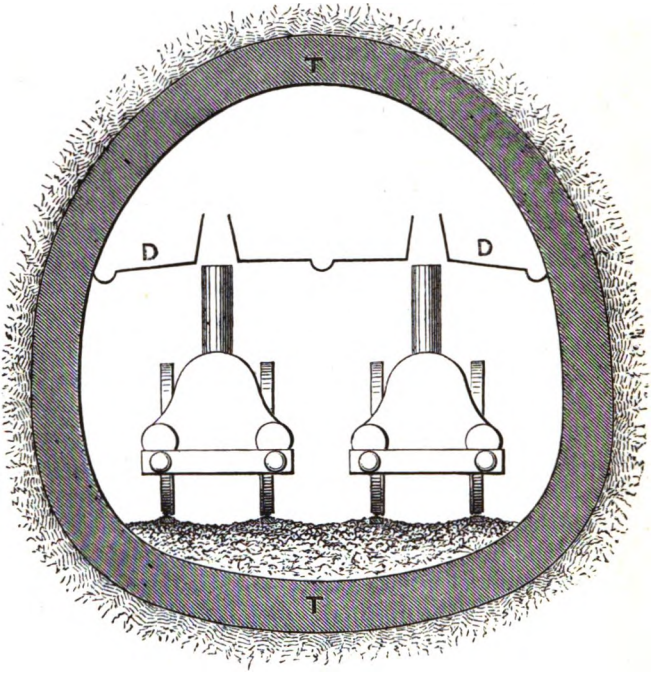
ought to be allowed, namely, ⅔ cubic foot in a minute. Taking the case of a compartment of a first-class carriage containing eight persons, there would be in it 300 cubic feet of air to start with. The eight passengers would require 5½ cubic feet per minute. It would be nearly an hour before the air would get vitiated; but allowing twice as much as he had mentioned, it would not become unpleasant in much less than half an hour, so that no artificial ventilation would be required until the train reached about the middle of the tunnel, from which point the air in the reservoir might be used. For a train of six carriages, containing one hundred and forty-four persons, 96 cubic feet per minute would be required. It might be assumed that the journey would not occupy more than fifty minutes, so that there would be twenty-five minutes during which the carriage would have to be ventilated, and the supply required for that purpose would be 2,400 cubic feet. The reservoir containing such a supply need not be much larger than a single compartment of an ordinary carriage. He thought, however, that the other plan would be sufficient, and that the ventilation of the tunnel might be carried on by natural means.

Mr. Barlow, Vice-President, said the members were much indebted to the Author for having brought forward a most interesting subject for discussion—a subject daily acquiring greater importance, both in this country and in foreign countries, and especially in London. The great distinction between the two processes of natural and artificial ventilation had been pointed out. Natural ventilation was understood to be that by which the hot-air currents were carried out at the top of the tunnel, and the cold air came in at the bottom, without mixing; which was accomplished with a very low amount of power. In the other case the bad gases were first mixed with the good gases, and artificial ventilation was adopted to dilute the whole of the mass with a sufficient quantity of fresh air to make it breathable. Such being the case, the point to be aimed at was to keep the gases separate. He had had the subject under consideration, and a method of accomplishing the object had suggested itself to him (Fig. 2, page 66). If T T represented the section of a tunnel, a division, D D, formed of iron, would be placed across it. Over the line of the engine chimneys there would be openings, the sides of which might be from 18 inches to 2 feet high, and inclined inwards. The carbonic acid and other products of combustion would be forced through these openings by the steam blast in impulses occurring four times for each revolution of the driving-wheel. The bad gases from the engine were projected

Digitized by Google

into the tunnel with considerable force, a force which was at present wasted. The effect of the proposed plan would be to drive the gases into the upper chamber, where they would no longer have the power of mixing with the other air of the tunnel. In tunnels of moderate length he believed that no other arrangements would be required, as the bad air would make its own escape. In that way not only would the bad gases go out at the top, but the engine was drawing in pure atmospheric air at the rate of 157 feet for each pound of

FIG. 2.



coal consumed. By thus utilising the power of the engine which was now wasted, the ventilation of the tunnel might be effected. He could quite imagine that in a tunnel 20 miles long it might be desirable to assist the movement of the bad gases from the upper chamber, by the employment of fans or otherwise. When two engines were in the tunnel at the same time, going in opposite directions, the movement of the air along the upper chamber would only amount to 48 feet in a minute, so that little power would be required to overcome it. Instead of an enormous power, as suggested by the Author, being required for twenty trains a

Digitized by Google

day, he thought that forty trains might pass in the day, without any other power than that of the waste power of the blast pipe, by simply adopting the arrangement he had suggested.

Dr. SIEMENS remarked that the plan proposed by Mr. Barlow was ingenious; but it would be purchased at the cost of two lines of valve, which would be a serious consideration, though not presenting an insuperable difficulty. Another plan had some years ago occupied his attention. When the Metropolitan line was in course of construction he was consulted, through Mr. Fowler, Past-President, as to some means of preventing the emission of the products of combustion, and he then proposed a plan by which an ordinary locomotive might run through the tunnel without being accompanied by the emission of any such products. The plan consisted simply in filling the fire-box with a clamp of bricks, so arranged that between the masses of brick innumerable channels were provided through which air might circulate and rob the brickwork of its heat in order to communicate it to the boiler. It might appear, at first sight, that the quantity of brickwork required for such a purpose would be enormous, but a little consideration would show that that was not the case. Fire-brick had a heat capacity about equal to that of water of the same volume; therefore if a cubic foot of brickwork was heated 1° that heat would suffice to heat a cubic foot of water 1°. But the brick had the advantage of being susceptible of being heated 1,000° above the standard which it must retain to evaporate a cubic foot of water. The question was, how many cubic feet of water were required to be evaporated, in passing from Dover to Calais. Taking as the rate of evaporation 5 cubic feet per mile, and taking the length of the tunnel as 30 miles, that would give a total evaporation of 150 cubic feet of water, and the brickwork necessary to yield that amount of heat would be 150 or 160 cubic feet, which would weigh about 17 tons, constituting a mass 6 feet by 6 feet by 10 feet, if one-half of it was allowed for air spaces. He proposed to heat the brickwork at the station in a furnace, and to lift it bodily, being clamped with iron, into the fire-box of the engine, where it would be fixed by bolts. Currents of air would be directed through it at the place of the ordinary fire-door, which, passing through the tubes of the boiler, would produce steam. At the end of the journey the engine would go over an empty pit, where the mass of brickwork would be lowered by an hydraulic ram, to be heated again for another journey. The boiler would, at the same time, be filled with water at 300° Fahr., so that evaporation would at once commence under the most favourable conditions.

Digitized by Google

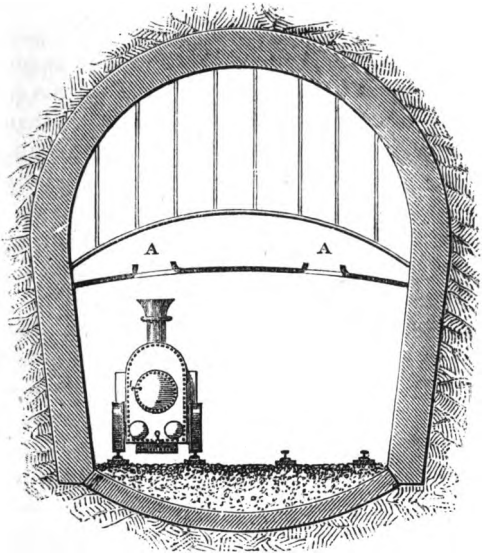
If the proposed scheme of the Channel Tunnel were ever carried out, he thought this plan ought to be fully considered, because he saw no difficulty in carrying a store of heat sufficient to take a locomotive engine from Dover to Calais, whereby mechanical ventilation would be saved and a wholesome atmosphere insured in the tunnel.

Mr. LONGRIDGE said that Dr. Siemens' plan appeared to be ingenious, but not practical. To take such a mass of brickwork, at a temperature of 1,200°, from a furnace, and place it in a locomotive engine for every train, there being thirty or forty in each direction every day, would, he thought, be a difficult operation. He did not see how such an amount of brickwork could be packed into a space of 432 cubic feet with sufficient spaces between the bricks to enable them to give out the heat. He had supposed two-thirds space and one-third brick, and he thought it would be exceedingly difficult to keep up the abstraction of heat, even from that, to anything like the extent required for a uniform speed. It would not, he thought, be wise to depend for the working of long tunnels upon any such complicated system. He agreed in the general idea put forward by Mr. Barlow, but he did not think it necessary to have the valves which had been suggested; nor did he believe that with the use of those valves, without some assistant power to pump the air out, the gases would be carried off to the extent required. The gases would rush up with considerable force, and at a high temperature. Take the case when the train was 10 miles from the end; they would then have to get out, and long before they had passed through the 10 miles they would be cold, and their specific gravity greater than the air below; and if there were no means of pumping them out they would stagnate. He approved of the idea of a diaphragm, as suggested by Mr. Barlow, and also dividing the tunnel longitudinally into sections, as proposed by Mr. Bell. The latter principle was a very old one, and had been adopted in coal mines where great lengths had sometimes to be ventilated. Instead of having elaborate passages through the brickwork, he would suggest that the tunnel should be made a little higher, and be divided by a double diaphragm, leaving a space between A A, Fig. 3, into which the gases and steam should pass. The space between these diaphragms should be divided longitudinally into sections, say each 1 mile long, and each section connected with an air-duct, constructed by dividing the space above by vertical partitions, as in Fig. 3. Taking a central length of 2 miles, 1 mile of the air would go through one passage, say to the north, and another mile through another passage to the south. A certain

Digitized by Google

amount of gases would then have to be carried 10 miles without being mixed with the surrounding atmosphere; the next 9 miles, and so on, until there was a separate flue for each compartment of the tunnel. There was but a short run to deal with, and a small quantity of gas to be got rid of—chiefly carbonic oxide, nitrogen, and steam, with a small portion of sulphurous acid. Not a hundredth part of the total amount of air would have to be passed through if it were diluted with all the gases given off by the locomotive. Therefore the system of placing a diaphragm to divide the pure from

FIG. 3.



the impure air was a good one for ventilating long tunnels. Before hearing this Paper it had not occurred to him that there would be any difficulty in ventilating a tunnel 20 miles long, but the Author's remarks had placed the matter in a new light. The Author, however, was, he thought, in error in giving 8½ parts in 10,000 as the maximum vitiation to be allowed. He thought no one should complain of having to pass twenty minutes in a railway carriage in an atmosphere which he was willing to breathe for three or four hours in a theatre. Nor should he complain of 25 parts in 10,000, when he remembered the condition of the atmosphere of the cabins of the steamers crossing the Channel. Certainly a passenger in a Metropolitan District railway third-class smoking carriage had to breathe

Digitized by Google

an atmosphere much worse than 25 parts in 10,000. It appeared, from some experiments recorded in the Philosophical Transactions for 1808,[1] that the amount of carbonic acid gas that would produce asphyxia was 9 per cent. If the air in the Channel Tunnel could be kept down to 25 parts in 10,000 he thought that no one would have a right to complain. Supposing a train to enter each end every forty minutes, and to travel at the rate of 30 miles an hour, and the current of air 10 miles an hour in the same direction, the adulteration would be, after the exit of the third train at the end of the tunnel, about 13½ per 10,000. If the current of air were in the opposite direction the result would be different. The effect of the first train in that direction was to adulterate the air the whole length of the tunnel, but only to the extent of 3·3 parts in 10,000; the next train added 3·3 parts; the next the same; and so on: but adding all the adulterations together, from the trains passing in both directions, they could not amount to more than 23 parts in 10,000. This would be the case with engines burning 35 lbs. of fuel per mile, and working every forty minutes from each end. To pass a current of air at 10 miles an hour through a tunnel 20 miles long was no doubt a serious matter, and would require 600 HP., effective. To work engines of that power continuously would of course involve serious expense; but by adopting the system of splitting the air, as in collieries, he believed that a 60-HP. engine at each end of the tunnel would suffice. He did not think it worth while to consider the questions of the difference of barometric pressure at the two ends of the tunnel, the direction of the wind, and the like. Nor was the absorption of carbonic acid gas by water in the tunnel worth consideration, since the water could only absorb its own bulk of the gas. In the year 1850, Mr. Goldsworthy Gurney proposed a mode of ventilating collieries by a steam jet, which at that time was strongly advocated by many people. In a paper which he had read before the North of England Institute of Mining Engineers,[2] upon the action of the steam jet, he showed that as a means of moving air at anything like a high water gauge it was most extravagant and expensive. There was a certain proportion necessary between the diameter of the channel into which the steam jet played and its length, which to give a maximum effect was about 8 to 1; and he found that the smaller the diameter of the jet, or the more they were subdivided, the greater were the results obtained. Also the

[1] *Vide* page 249.

[2] *Vide* Transactions of the North of England Institute of Mining Engineers, vol. i., Oct. 1852.

Digitized by Google

higher the steam pressure the greater were the results. He found that working with a water gauge of 1½ inch, a jet of $\frac{7}{100}$ inch diameter, a blast pipe of 2 inches, and a pressure of 5 lbs. of steam, gave 165 cubic feet per minute of air moved for each cubic foot of water evaporated per hour. With a pressure of 60 lbs. the result was 241 cubic feet per minute. Taking that extreme case, and assuming that in a good compound engine the expenditure of fuel was 3 lbs. per effective HP., it would be found that the steam jet for each HP., as measured by the water evaporated, moved 101 cubic feet of air per minute. He need hardly say that that was a most expensive mode of applying power. He also tried a comparison with locomotive engines, because it was said that the blast-pipe was such a powerful mode of creating a current; but he found that the quantity of air moved for each HP. expended was not more than from 15 to 20 cubic feet per minute. He was convinced that as a motive power the steam jet was an entire mistake. Assuming that in a good compound engine 3 lbs. of coal per hour would produce 1 HP. effective, this would evaporate 27 lbs. of water, equal to 0·42 cubic foot; therefore the quantity of air moved per minute in the cases referred to, say with a jet of $\frac{7}{100}$ inch steam boiler pressure, was $241 \times 0{\cdot}42 = 101$ cubic feet per minute. In the case of the locomotive engines, the effect stated was deduced from an experiment recorded by Tredgold, made on the Caledonian railway on engine No. 15, and it resulted from the calculations given at length in the Paper above referred to that the expenditure of steam passing through the blast pipe was 84 cubic feet per hour, and the quantity of gases 4,044 cubic feet per minute; which, when reduced to the temperature and density of air at 62°, would give 3,040 cubic feet of air, or 36½ cubic feet per minute for each cubic foot of water per hour. In another experiment on the Great Western railway, the equivalent quantity of air was about 50 cubic feet per minute per cubic foot of water evaporated per hour; and comparing this with the effect in a compound engine as before, there would result:

$$36{\cdot}5 \times 0{\cdot}42 = 15{\cdot}1 \text{ cubic feet of air per HP.,}$$
$$50{\cdot}0 \times 4{\cdot}2 = 21{\cdot}0 \quad \text{,,} \quad \text{,,} \quad \text{,,}$$

as compared with a good compound engine.

Mr. Jos. Tomlinson observed that the subject of tunnel ventilation had been forced upon him at the end of 1872, when he joined the Metropolitan railway, and for many months his attention had been devoted to the question.

The schemes submitted by the inventing public to cure the evil

Digitized by Google

would have cost as much money, simply to try each on a small scale, as he had spent to keep the line in order. They had been mostly of an impracticable type, some depending on one thing and some on another, but mostly asking what would be a simple matter were space, land, or authority of Parliament available, to wit, make shafts and openings. The same appeared, virtually, to be the plan of the Canadian gentleman; one sage person seriously recommended that a frame, fitting the tunnel, should be fixed on two engines, one on each line, which was to be run through after the trains had ceased at night. One of the previous speakers advised making a tunnel and then finding out a means to ventilate it, which he thought would be got over; but he could hardly agree that such advice should be followed as regarded long tunnels. It appeared that was exactly what had been done with the Metropolitan railway, to correct which error a vast amount of labour and money had been expended. The Metropolitan railway, as constructed, had been practically shut up, as one tunnel from King's Cross to Edgeware Road, for something like 2¼ miles; but it was soon found that the effort to ventilate itself was a failure, and openings had to be made. A large opening was cut about halfway between King's Cross and Gower Street, now a block station. Again, two houses had to be deprived of their front gardens, and openings about 25 feet square made down to the platforms at Gower Street. Portland Road Station had to be denuded of its domes, and opened to the rails in two places; and Baker Street had been opened to the external air by the making of the junction with the St. John's Wood railway. In addition, openings into the roadway, 25 feet by 4 feet, had been cut where possible; and still, as the trains became more frequent, there was imperfect ventilation. In dealing with the question how to improve this state of matters, the difficulties, at first, appeared to be almost insurmountable, owing to the frequency of the train service at the busy periods of the day, when as many as fourteen trains passed each way in the hour, as from the churning of the air by the trains, it was almost impossible to arrive at any data to form a judgment of how to set to work. He determined, however, that something should be done if possible, and accordingly experiments were begun. His first efforts were made with a couple of anemometers placed in various positions in the tunnels; but their erratic and irregular performances, under seemingly similar circumstances, gave no result of any value, so he had recourse to naphtha lamps hung about the tunnel wherever possible, clear of the trains when passing. These also gave such contrary indi-

Digitized by Google

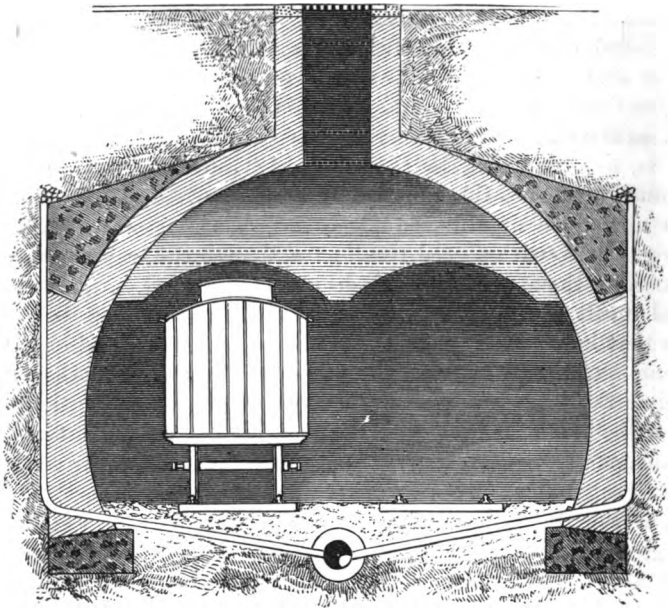
cations of the currents of air that he was almost giving up in despair. At last, by close observance, there appeared what seemed a clue, and that was that there was always a sensible current in the direction of a train, in front of it, near or at the top of the tunnel; but the bottom and centre gave no clue to enable the great body of air to be dealt with. The attempt was therefore made to discover to what extent this current at the top was affected by the openings in the roadway above; but no discharge of any amount took place. Next, a large bonfire was kindled of greasy waste, oil, &c., at the Edgeware Road end, with a westerly breeze, and on walking over the openings intended for ventilators, next to nothing was evolved into the street, but the cloud of smoke and fume was taken clean through Baker Street and Portland Road, and was sensibly felt at Gower Street. The next step was to try and stop this top current at the openings, and, as it were, cut the tunnel into several tunnels, by fixing screens across, and so expel, by the piston-like force of the train itself, as much air as possible (Figs. 4 and 5, pages 74 and 75); and this was now done at thirteen places between Edgeware Road and King's Cross, with a good result; for, though the trains were more numerous, the atmosphere was decidedly improved. Another beneficial result of the cross diaphragms, if they might so be called, was that immediately a train had passed half the opening a very strong current of external air was carried down into the tunnel behind the train, which continued, gradually decreasing however, until the train had reached the succeeding opening, and in the meantime the upward current of heated or vitiated air went out on the other side. This alternate upward and downward current was repeated on the passing of each train, so that the lighter vitiated air was largely expelled without much affecting the bulk below. The scheme had also effected a great change for the better at the stations. Before the screens were put up each train arriving at the stations had been followed by a current of foul air; but now that was intercepted to a great extent, and delivered into the external air by impinging on the screen and being shunted upwards. The scheme of utilising the pneumatic tube as a means of ventilating, had only been in operation for a few weeks. While in use between 9 A.M. and 10 A.M. the result had been effective.

With regard to the Paper, he did not see any reason to differ from it, except that he thought the standard of purity need not be fixed so high, and therefore the calculations would bear reduction to a revised standard.

Digitized by Google

The remarks of the Author on the Mont Cenis Tunnel had been corrected by Dr. Pole, as to the manner of its ventilation, and there could be no doubt that the centre was the proper place to try and effect the clearance of foul air. The question of ventilation for so long a tunnel as that proposed under the English Channel certainly appeared to offer serious difficulties; but the plan suggested by Mr. Bell seemed to be a way of solving them, as it would virtually make a series of shafts. The plan, though costly in itself, would enable ordinary locomotive engines to be used, as they could carry water enough to condense to the same extent as

FIG. 4.



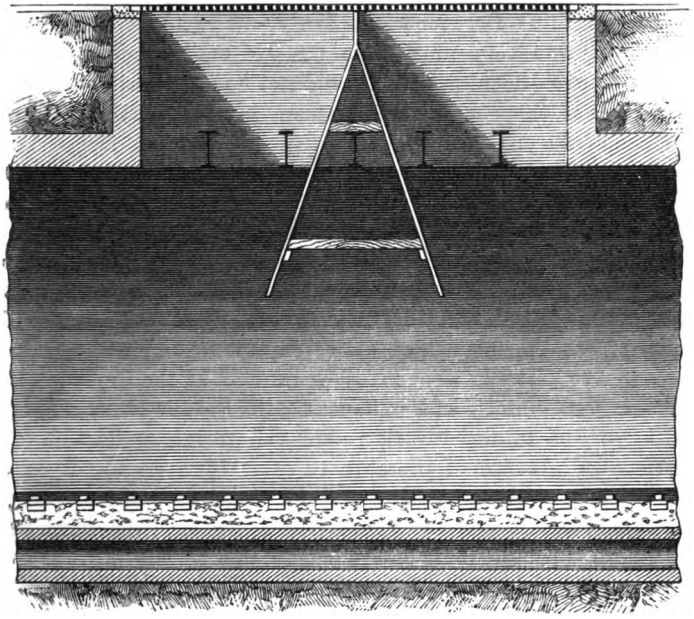
METROPOLITAN RAILWAY. VENTILATING SCREEN. Scale, $\frac{3}{32}$ inch to 1 foot.

on the Metropolitan railway, and so relieve the tunnel of nearly all discharge of steam; and as it was fair to assume the walls of the tunnel would never be dry, a large portion of the carbonic acid, not carried off by the air-ways, would be taken up by them. There was no question that the presence of steam would relieve the sensations of foul air; but, as it was necessary to see, freedom from the watery vapour would be a great advantage. In fact, the presence of escaped steam in foggy weather, on the Metropolitan railway, caused some inconvenience, though, practically, the air was better for breathing. The Author seemed to be in

Digitized by Google

favour of large tunnels to render ventilation easy; but to this he did not agree, as his experience with single-line tunnels, with trains working both ways (twelve an hour), was that they were always perfectly free and pure, whereas double tunnels of half the length, with trains on both roads, were frequently very foul. This was particularly observable when the air was heavy with moisture and there was no wind, as then it was with difficulty that anything could be seen at 100 yards in the double tunnels, while the single ones were practically clear. Comparisons of coal mines with railway tunnels were not admissible, as the conditions

FIG. 5.



METROPOLITAN RAILWAY. VENTILATING SCREEN. Scale, $\frac{3}{8}$ inch to 1 foot.

were totally different. The shafts being chimneys, and of course of great height, the difference in weights of air in the up and down-cast shafts alone gave power almost without assistance, whereas with most railway tunnels there was only a difference of a few feet, and this was especially the case on the Metropolitan railway.

As regarded the health question on that railway, he found that ninety-five enginemen and firemen only received last year from their club the sum of £26 5*s*., or equal to 1·28*d*. per man per week, sick-money, and this included loss of time by trifling

Digitized by Google

accidents. He was informed that the same immunity from sickness also prevailed with traffic servants, more especially on the section of the line where the difficulty of ventilation existed. He considered the scheme of Mr. Barlow would not work in practice, as the blast would be interfered with, and the products of combustion would be thrown back into the fire-box, and cause great inconvenience, at least on the foot-plate; besides, the efficiency of the boiler would be lessened. No plan which gave the escaping currents any work to do would, in his opinion, be suitable. The plan was somewhat similar to one recently submitted to him, but it could not be entertained, as the danger from any temporary structure would more than balance any gain over the present plan. He did not think Dr. Siemens's plan could be adopted, and, in his opinion, it was very unsuitable for use on locomotive engines. There was one difficulty which could not be got over, and that was the control of the generation of steam in case of the failure or stoppage of the engine.

Mr. T. W. Bunning said the extreme divergence of opinion elicited by the discussion, and the varied and startling nature of some of the means proposed to ventilate long tunnels, induced him to say a few words. The excellent observations of Mr. Sopwith, who suggested a vertical brattice, and the practical experiments of Mr. Tomlinson, led him to think that many of the members had witnessed experiments which indicated how a tunnel of any length might be ventilated. Not many years ago, at the Crystal Palace a scheme was exhibited for exhausting the air out of a tunnel, and putting a sort of brushwork round the train, sufficiently tight to allow a difference of pressure to exist between the front and the back of the carriages, so as to draw the train along. The plan he would suggest was to reverse this, to divide the tunnel by a diaphragm throughout its entire length, and attach the brushwork behind the funnel of the locomotive, so as to fit one half of the tunnel; this would push the foul air out in front, and draw the fresh air in from behind. It would certainly be a costly plan, but it would at least be a practicable one, which he feared would not be the case with some of the schemes proposed.

Mr. Charles Douglas Fox was glad that some information had been afforded with regard to the Metropolitan railway, and he hoped that the tentative efforts made to improve the ventilation of that line might be more successful than they had been hitherto. He thought the plan adopted would be more successful if combined with a longitudinal bratticing of the tunnel, for which, owing to the removal of the broad gauge,

Digitized by Google

there should be sufficient space between the rails. The condition of the Metropolitan District railway was at present very trying to those who had to travel much by it; and here there was no space for bratticing, except near the roof, and above the level of the top of the carriage doors. He believed, however, that even this partial separation of the air currents would prove of much advantage. He could quite indorse Mr. Tomlinson's statement with regard to the churning of the air, which indeed was only what might be expected in a double tunnel with so many trains running rapidly in opposite directions. He thought the Author was in error in suggesting that, if mechanical ventilation was to be introduced, the double tunnel would nevertheless be the better form to adopt. Certainly, if a tunnel were left to ventilate itself, the larger the area the better; but, if mechanical ventilation had to be used, it appeared to him that it would be better applied in the case of two single tunnels, than in the case of a double tunnel. When mines were being opened up, it was the common practice to drive two headings parallel with one another in order to obtain the proper current of air, and he thought that the same principle ought to be applied in railway tunnels of great length. With regard to the question of working, he was disappointed to find the Author, for whose opinions he had much respect, making what he could not but consider retrograde suggestions. One of them was a modified adaptation of the atmospheric system. When such a proposal was made he thought it advisable to refer to what one of the fathers of engineering science had stated. In a report made by the late Mr. Robert Stephenson, dated April 9th, 1844, to the Directors of the Chester and Holyhead railway, the following amongst other conclusions were arrived at, viz., "The atmospheric system is not an economical mode of transmitting power, and is inferior in this respect, both to locomotive engines, and to stationary engines with ropes." And again, "On long lines of railway the requisites of a large traffic cannot be attained by so inflexible a system as the atmospheric, in which the efficient operation of the whole depends so completely upon the perfect performance of each individual section of the machinery." The difficulties of the atmospheric system, especially with reference to keeping the longitudinal valve tight, were a matter of history. If that proved so difficult upon a line $3\frac{3}{4}$ miles in length, what would it be in the case of a tunnel 22 miles long? He was also surprised at the suggestion, from a practical man like the Author, that the tunnel should be divided into lengths, a valve placed at the end of each length, and a man

Digitized by Google

stationed there to open it as the train passed. Considering that the tunnel would be required for very heavy traffic, he thought that something more mechanical, less expensive, and less liable to mistakes and breakdowns, would be necessary. With regard to the pneumatic system, he was of opinion that, for short lines in tunnel, and for moderate rates of speed, it had great advantages. By its means the train could be driven by the same process that ventilated the tunnel; the fans could be easily provided in duplicate, as in the case of mines, and the doors at the end of the tunnel might be simple, and easily replaced. The weight of the locomotive was altogether saved, a matter of special importance where trains were short, and stoppages frequent, and the danger of collision was absolutely avoided. The leakage, in the case of the pneumatic system, was of minor importance compared with the atmopheric leakage in consequence of the great difference of pressure, which was not more than 4 ounces in the former as against 15 or 16 lbs. in the latter. In a long tunnel, however, like that proposed under the Channel, where there could not be intermediate pumping stations, and a speed of at least 30 miles per hour would be necessary, such a system was practically out of the question. It was true the air might be considered as an elastic rope; but as Mr. R. Sabine had pointed out, in a paper read before the British Association,[1] it was not a light one, weighing as it did more than a wire rope with which the same work could be done; and in such a great length and at high speeds the advantages which would be otherwise gained would be lost by friction on the sides of the tunnel. The system of underground haulage by ropes was extending every day, and great advantages were found to arise from it, but those who had had most to do with it would be the last to recommend this plan for working an important passenger traffic. There was nothing more liable to breakage. Such breakages could be soon repaired in the case of a mine, but if a fracture occurred in the middle of a tunnel 22 miles long the delay would be considerable, and in such a length accidents of this kind might be constantly expected. There was also the difficulty connected with twisting, which, together with the friction on the sheaves, caused the life of a rope laid down and used in the way proposed to be very short. It would be found that the mere friction which the rope had to overcome, taking it at about one-twentieth of its weight, would absorb more than the proper strain which ought to

[1] *Vide* Report, 1870, vol. xl., Notices and Abstracts, p. 227.

Digitized by Google

be put upon it, and would amount to some fifteen times the weight of the train. If the Channel Tunnel was to be really useful, trains ought to be able to run through without delay, and anything which involved changing the system of working at the two ends of the tunnel must be a serious drawback. He therefore thought the locomotive would be necessary in some form or other. By the use of single tunnels, and with a fan at one end of each, a great improvement could be made in the air at a moderate expense. In order properly to ventilate a tunnel of such length, if worked by ordinary locomotives, the air would have to be driven at 20 miles an hour, and, if that were done, the expense of the pneumatic system might as well be incurred. But he believed that was altogether unnecessary, and that arrangements could be made, by which locomotives should consume less air, and then moderate artificial ventilation, at a low speed, superadded to the natural ventilation, would effect the purpose desired.

Mr. STEPHENSON, President, said he believed, from the discussion that had taken place, that the difficulty connected with ventilation would probably be one of the least of those to be contended with in connection with the proposed Channel Tunnel. With regard to collieries in the North of England, it was well known that volumes of air were passed down into them for the purposes of ventilation, the amount being simply a question of power, and he thought that similar arrangements might be adopted for a tunnel.

Mr. J. B. HUNTINGTON observed, through the Secretary, that the project of ventilating a tunnel 22 miles long was perhaps too ambitious at the present moment, seeing that engineers were not yet in a condition to ventilate a tunnel $\frac{1}{2}$ mile or even $\frac{1}{4}$ mile long, as was evidenced on the Metropolitan railway between any two stations from Bishopsgate to the Bishop's Road, and also on parts of the Metropolitan District railway. Considering the number of trains which ran to and fro on those railways, twelve to fourteen every hour each way, they must be regarded as exceptional cases; notwithstanding which, it was a reproach to the engineering talent of the time that nothing satisfactory had been done towards their ventilation, than which nothing seemed to be more simple. The ventilation of extensive coal mines presented no features which were regarded as insuperable. In many of these cases the quantity of air set in motion from long distances far exceeded any demand on the Metropolitan or the Metropolitan District railways. In Italy, he had superintended large sulphur mines, worked on

Digitized by Google

the same plan as those of coal, where the vapour of the sulphur was often oppressive, if not dangerous, when disregarded, and where the galleries and workings were 2,000 yards in length, and at a depth of 200 yards from the surface no difficulty had been found in ventilation; the simple plan being invariably successful of having a downcast shaft and an upcast shaft, of different surface levels, connecting with all the galleries and workings of one system, and which kept the air perfectly wholesome. On the Metropolitan railway every plan seemed to have been tried but that of two levels for the in and the out passage of the air. Seeing that the openings at the stations, or elsewhere, were practically on the same level, the current which would induce ventilation was simply null; also, it was not judicious to ventilate towards the stations where passengers resorted. Yet he did not hesitate to state, from analogy with coal and other mines, that the erection of a high shaft halfway along each tunnel would effect a rapid withdrawal of the foul and noisome air, which passengers were now perennially condemned to breathe. In fact, a fortnight's receipts of those railways devoted to this object would settle the matter successfully. Once having determined the plan, the dimensions and inner economy of the erections would become a mere affair of calculation.

The main discussion seemed to be directed to the interesting problem to be solved as to the best method of ventilating the proposed tunnel between England and France, it being taken for granted that, if *à priori* cautious steps were not used to secure this necessity, the tunnel itself would be a foolish work. The length was stated to be about 22 miles, and it had been suggested that hourly trains should be provided for, and a double line of rails. Once more it might be repeated, that all this was on too ambitious a scale, when a small thing, well tried first, could be easily extended, if required. It was necessary to show that hourly trains were likely to be wanted. Probably four trains each way in twenty-four hours were all that should be reckoned upon. These could convey from twelve hundred to thirteen hundred passengers daily each way, which would exceed the present traffic; therefore these trains could be so arranged that only one should be in the tunnel at a time, at intervals of perhaps three hours, which period, as business or occasion demanded, might be shortened into two hours, giving six trains daily each way, conveying perhaps two thousand passengers. It must be granted that locomotive power could not be dispensed with at present, and that extreme vitiation of the air must necessarily be the consequence of the employment of fuel-engines. But this vitiation need not be allowed to extend through

Digitized by Google

the whole area of the tunnel. It originated principally and practically at the extremity of the funnel, and, in fact, for a time the foul air (such as became injurious) remained suspended at the top of the tunnel. If, therefore, it could be there collected, and prevented from descending to mix with the air about the carriages, the first step would be made towards ventilation. Something of the kind had been suggested, where the lower stratum of air was cut off from the upper stratum of foul air by a horizontal screen, having a longitudinal aperture for the funnel of the engine. Either this, or some plan similar in effect, could be easily erected, and it might be even worth while to test it by actual experiment in some known tunnel, as it would not be costly. Now the question was, how to remove the vitiated air, seeing that it was 100 yards below the surface, and 11 miles distant from the mouths of the tunnel at the centre. It would certainly assist the ventilation, if it were to be carried on at the same time from both extremities. It was not necessary to have doors, nor blocked sections of the tunnel either crosswise or lengthwise. All that would be required would be to have the tunnel so divided that each division of, say 1 mile each, should separately discharge its own vitiated air. It was certain that the pure air would easily enter the mouths, and, following the descent, fill the lower part, and also enter the upper part, so as finally to sweeten it, provided that the outlets from the latter could effect the work intended. Several shafts on shore, of sufficient elevation and diameter to carry off, in a given time, say one hour and a half, the foul air contained in a length of 1 or 1½ mile of the tunnel, might by means of pipes be connected with the foul-air space, each pipe acting separately in divisions, into which the foul-air chamber might be divided. Whether these pipes should be laid inside the upper space, or be cut in the chalk, was a matter of detail and economy. The shafts, independent of the normal draught due to the difference of elevation of their caps above the mouth of the tunnel, might be furnished with furnaces or blowers, after the approved manner used in mines.

It had been observed that probably the trains running only one way or the other every two or three hours would suffice for the traffic. Therefore a tunnel with a sectional area of about 270 square feet, or 30 square yards, would be large enough. Of this not more than 8 square yards would contain the vitiated air. The tunnel might be taken at 40,000 yards long; so that $8 \times 40{,}000 = 320{,}000$ cubic yards of air would have to be removed in a certain time. A locomotive, going at the rate of 20 miles per hour, would leave behind about 1 cubic foot of foul air per lineal

Digitized by Google

foot, that was, about $\frac{1}{7\frac{1}{2}}$nd part, or in an extreme case, say $\frac{1}{4\frac{1}{2}}$th part of the upper space. But on the supposition of twelve trains daily, the upper space would be only vitiated to the extent of $\frac{1}{4\frac{1}{2}} = \frac{1}{4}$th of their capacity. Hence, if it were assumed that 320,000 cubic yards had to be discharged in twenty-four hours, the ventilation would be perfectly effected; for the foul air was always flowing into the pipes, and it could never again mingle with the pure air replacing it. Therefore, assuming sixteen shafts, eight in England and eight in France, each drawing 20,000 cubic yards in twenty-four hours; those shafts which drew from the farthest distance would have to be chiefly considered, and indeed those adapted to the chambers nearer shore could be made auxiliary by connecting channels. It could be shown that with a pipe only 3 feet in diameter, and a draught of 54 feet per minute, the given quantity could be discharged, and to obtain this velocity there would be the elevation, the furnace, and the blower. Even if the cost were equal to the maintenance of two or three additional locomotives, it would be justified by the results.

In conclusion, should it be deemed advisable to construct another line of railway, it seemed preferable to make another parallel tunnel of 30 square yards sectional area, and furnished with independent ventilators. From observations, both in England and in France, elevations above the tunnel mouth of 100 yards could be bored vertically through the chalk, which of themselves would prove very efficient upcast shafts.

Mr. W. Low remarked that, in his opinion, the Author was wrong in affirming that a long single tunnel with two lines of rails could be ventilated more easily than a twin tunnel with a single line of rails in each. In a long tunnel having two lines of rails without any intermediate shafts, and with trains passing continuously in opposite directions, the foul gases from each train would accumulate in the centre of the tunnel, and it would be utterly impracticable to extract this air by means of a fan, and at the same time continue the traffic; that was to say, no fan could be put up, which would extract the air against the run of the trains. Therefore, to extract the air from one end of the tunnel in two hours, as stated, it would be necessary that no trains should pass through the tunnel during that time. That would reduce the number of trains that could pass through a tunnel 22 miles in length, such as the proposed Channel Tunnel, in twenty-four hours, to eight at the most; whereas, by adopting a twin tunnel, ninety-six trains might pass through, forty-eight each way, every twenty-four hours, without the least difficulty whatever. The

Digitized by Google

trains being propelled in one direction continuously, would cause the air to be put in motion, passing into the tunnel at one end, and out at the other, the trains themselves being the ventilating power, instead of the costly and impracticable process described in the Paper. His views on the subject of the "Ventilation of the Channel Tunnel Railway after Completion,"[1] had been embodied in a Report, of which a copy would be found in the library of the Institution.

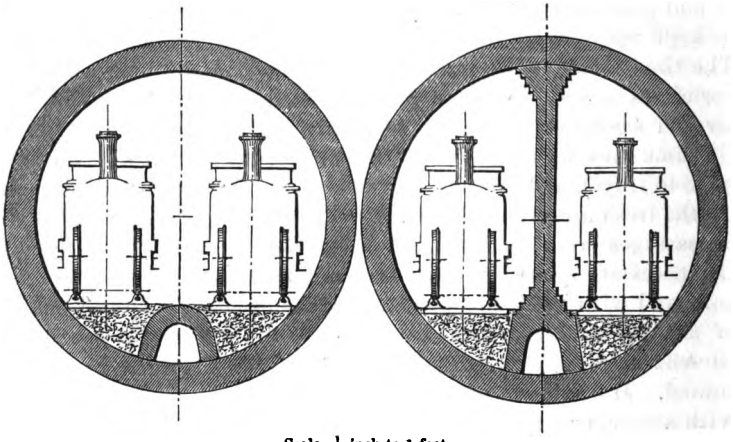
Mr. COWPER wished particularly to direct attention to the fact that in long tunnels the friction of the air was excessive. He thought the observations made by some of the speakers, and the proposals for dividing the tunnel by a number of diaphragms with small passages or pipes, would hardly have been entertained if the full friction of the air had been calculated in each case. With a good traffic through the tunnel the quantity of foul gases left in every part was such that a quick current must be kept up to take them away before another train came along. The time between two trains was not sufficient in a long tunnel to permit of any slow process being trusted to for getting the foul air and smoke out, for they would always mix together owing to the time they would be in the tunnel and the distance they would have to travel, and must be driven out as a wad or plug of foul air by the fresh air supplied from the end of the tunnel. Small pipes or passages were inadmissible, from the impossibility of forcing the necessary quantity of air through them, at a reasonable pressure and with moderate power. He believed that the full section of the tunnel was much better adapted for obtaining a quick current than any arrangement of pipes or diaphragms in the tunnel. He did not think a long tunnel could be safely worked with a rope, or on the pneumatic or atmospheric systems. Ropes in tunnels had in almost all cases been given up; and the atmospheric system having proved a failure after long experience, gave no hope of its succeeding in long tunnels, where repairs would be difficult and tedious. There was, moreover, no room between the rails of the ordinary gauge to admit a tube large enough to yield the speed required, owing to the great friction of the air in the tube, so that it was impossible to use it. If, however, it was attempted to drive the train by a current of air filling the tunnel, and traversing it at the full speed of the train, a tunnel 15 feet in diameter and 25 miles long might be imagined, the train and air moving at 25 miles per hour, and then there would have to be a pressure of 2·56 lbs. per square inch, and 4,349 HP. would be

[1] Tract, 4to., Hughes and Son, Wrexham, 1873.

Digitized by Google

required, exclusive of the power to drive the train. If, on the other hand, a 3-feet pipe were laid on from the end to the middle of the tunnel, and it was attempted to suck out the noxious gases from the centre by that one pipe, that also would fail, because a nearly perfect vacuum kept up in that pipe would not take out a sufficient quantity of air. If a pressure of 50 lbs. per square inch were kept up continuously to blow the fresh air into the middle of the tunnel through a pipe 3 feet in diameter, it would only give a velocity of 0·93 mile per hour exit at each end of the tunnel, which would be quite insufficient to remove the gases if trains passed, say every hour. The power required in that case would be 3,000 HP. If the tunnel were for a double line of rails, the velocity with which the foul air would come out at each end would only be 0·42 mile

FIG. 6.



Scale, $\frac{1}{16}$ inch to 1 foot.

per hour, which would be insufficient. He agreed that a steady current of air was required for good ventilation through a long tunnel. It would never do to change the direction of the current of air, as great delay would arise, the total weight of the air in a tunnel 25 miles long for one line of way being 902 tons, and for two lines 1,765 tons. He considered that a speed equal to half that of the train would suffice, say 12½ miles per hour, in the same direction as the train going 25 miles per hour; then if there were two tunnels, each for a single line of way, the trains could be started at one hour intervals, and always run in good air; the pressure required would be 0·601 lb. per square inch, and the power 674 HP. for each tunnel. If the tunnel were for two lines of way, and the air traversed at the same speed, the trains could

Digitized by Google

not run in good air at less intervals than three hours, though if the trains were run into air that had already been partly vitiated the intervals might be somewhat shorter. The best plan for long tunnels would seem to be to make them large enough to allow of a division wall between two lines of way (Fig. 6), so that there would only be the expense of one large tunnel instead of two small ones, and the ventilation would be, as mentioned above, with two separate tunnels, the air traversing in the direction of the trains at half their speed.

Mr. V. G. Bell, in replying on behalf of the Author, observed that the general feeling appeared to be that the difficulties of the question had been hitherto greatly underestimated, and that the Author had thrown some light on the subject.

Regarding the alleged arrangements at the Mont Cenis Tunnel, the system could not be very efficacious unless the air pipes were of much larger size than the original tunnel would admit of. In pipes 3 feet 6 inches in diameter, the speed of the air must be about 70 feet per second, or 48 miles per hour, to produce an indraft into the tunnel at the rate of 1 mile per hour, which would be quite ineffective if the traffic were heavy. Dr. Pole had testified to the good quality of the air in the tunnel; but, apart from the evidence that it was very variable, it must be borne in mind that the traffic was small.

With regard to the quantity of air, and the power required, the Author had proceeded on what appeared to be a reasonable assumption, that with equal amounts of traffic the quantity of air to be supplied must be proportioned to the length of the tunnels, to give a certain standard quality to the atmosphere; whereas Mr. D. P. Morison had taken a fixed supply of 400,000 cubic feet of air per minute in all cases independent of these conditions. Dr. Letheby had given valuable information respecting the quality of the air in various localities, in general confirming Dr. Angus Smith's opinions quoted by the Author. He considered that 15 parts of carbonic acid in 10,000 might have been safely taken by the Author as a standard, instead of 8½ parts. Mr. André, Mr. Longridge, Mr. Sopwith, and other speakers, had also objected to so high a standard of purity being adopted; but in support of the Author he would quote, first, Dr. Letheby himself, who said he considered 10 parts of carbonic acid gas in 10,000 of air as the point where the atmosphere was getting bad; and, secondly, the general public opinion of the atmosphere of the Metropolitan railway, where the average was never so much, and the highest maximum was 16 parts. It must be borne in mind that carbonic acid gas was not the only, nor, by any means, the most noxious impurity generated by the combustion

Digitized by Google

of coal; its amount was only taken as a test of the quality of the air. If the proportion of carbonic acid were increased, that of sulphurous acid and of carbonic oxide were also increased in the same ratio, and both were poisonous even in minute quantities.

The objections to liquid fuel were their cost, and the danger attending their storage, transport, and combustion. Their use would also not affect the question of ventilation in principle, but only in degree. The difficulty of storing pure hydrogen gas in a sufficient quantity in a reasonable space seemed to be prohibitory. At the lowest, 1,095 cubic feet per mile would be required. The proposal to condense the carbonic acid gas by the use of lime had been alluded to by the Author. It was not easy to see how it could be carried out in practice; the expense would not be small, and, after all, the atmosphere would remain very deficient in oxygen. The proposal to carry fresh air for the use of the passengers should, in consistency, be also made for the combustion of the fuel, which would otherwise be very imperfect, and to provide for the platelayers employed in the tunnel. The plan proposed by Mr. Barlow would have a serious tendency to check the draught of the locomotive, especially if, for long tunnels, a valve were used. Without such a valve the products of combustion must be rapidly removed, or they would diffuse themselves into the atmosphere of the tunnel; and the same applied even with a valve, unless it could be made perfectly air-tight, which was difficult to conceive. The suggestion of fire-brick heaters instead of fires in the locomotives had been alluded to by the Author. The mass of brickwork must be of enormous weight and dimensions; it could not be more than 4 feet wide to be lifted up from below, as proposed by Dr. Siemens, in a railway of the ordinary gauge, and must therefore be 18 feet long instead of 12 feet as proposed. There would be loss in heating the bricks, and loss in giving out heat in the boiler; consequently the quantity of fuel consumed would be very great for the useful work done. Besides which the heated air and steam issuing from the engine would soon raise the temperature of the atmosphere in a long tunnel to an unpleasant degree, and would, after all, render artificial ventilation necessary. The plan proposed by Mr. Bunning would not only enormously increase the tractive resistance of the train, but would also have the effect of causing a down draught through the furnace of the locomotive, thereby destroying its efficiency. Nor would the trains carry off their own impurities with them, and so ventilate the tunnels, without other assistance in two single-line tunnels. The experience of the Wood-

Digitized by Google

head and other similar tunnels did not support this view. If it were correct, the state of the atmosphere surrounding the train towards the far end would become excessively bad.

The question of the relative advantages of one double-line tunnel and two single-line ones seemed greatly to depend on the system of ventilation employed, and partly perhaps on the conditions with respect to gradients of the particular case. On this point, as well as with regard to the proposal to abandon the locomotive in favour of the rope or the atmospheric system for working heavy traffic through a long tunnel, he was opposed to the Author's conclusions; but, looking at the exhaustive and clear manner in which the subject had been treated in the Paper, he believed the rejection of these conclusions would not detract from its value.

Mr. D. K. CLARK remarked, through the Secretary, that the ventilation of long and close tunnels, without any intermediate openings, worked by steam locomotives, could only be effected by artificially extracting the foul air. This might be done either on the "separate system," in which the gaseous products and steam discharged from the locomotive were collected and withdrawn, apart from the general air of the tunnel; or on the "dilution system," in which the refuse gases were mixed with the air of the tunnel, and the whole of the diluted mixture was exhausted. On the separate system, the volume required to be extracted was not a hundredth part of that which was required to be removed, on the dilution system. Besides, the separate system was capable of maintaining the atmosphere absolutely pure; whilst the dilution system was relative, and the air could only be maintained at a tolerable degree of pureness by a large expenditure of ventilating power. Taking an average consumption of 35 lbs. of coal per mile run by each train, the volume and weight of the gases produced by the complete combustion of English coal of average composition, containing 80 per cent. of carbon, and 5 per cent. of hydrogen, was—

	Cubic feet, at 62° Fahr.	lbs.
Carbonic acid	25·20	2·930
Steam, gaseous	9·50	0·450
Sulphurous acid.	0·15	0·025
Nitrogen.	115·29	8·536
	150·14	11·941

say, in round numbers, 150 cubic feet, or 12 lbs. of gaseous products of combustion, per lb. of coal:—amounting to (150 × 35 =) 5,250 cubic feet, or to (12 × 35 =) 420 lbs. of gaseous products per mile

Digitized by Google

of tunnel. These data gave, in round numbers, 1 cubic foot, or $\frac{1}{12}$ lb., of gaseous products per lineal foot traversed by a train. Again, the quantity of steam discharged from the blast pipe of the locomotive, for each lb. of coal, was, say, $8\frac{1}{2}$ lbs., occupying, at atmospheric pressure, a volume equal to 26·36 cubic feet per lb.; or a total of 224 cubic feet for each lb. of the fuel. Assuming that this steam was diffused, uncondensed, amongst the air and the other gases (which was practically the case), the quantity to be collected amounted to ($224 \times 35 =$) 7,840 cubic feet, or to ($8\frac{1}{2} \times 35 =$) 297 lbs. per mile of tunnel; that was, approximately, $1\frac{1}{2}$ cubic foot, or $\frac{1}{18}$ lb. steam, at atmospheric pressure, per lineal foot traversed by a train.

On the basis of the foregoing data, the following general proportions might be accepted for the air, gaseous products, and steam, constituting the atmosphere of a tunnel without draft, after having been traversed by one train:—

FOR ONE TRAIN.

In Tunnel.	Per lineal foot. Cubic feet.	lbs.	Per lineal mile. Cubic feet.	lbs.
Air	473	36	2,497,440	190,080
Gaseous products . . .	1	0·08	5,250	420
Steam	1·5	0·056	7,840	297

The gaseous products and steam together, for one train, amounted in volume to $2\frac{1}{2}$ cubic feet per lineal foot of tunnel, or 13,090 cubic feet per lineal mile; and the quantities corresponding to the number of trains per hour passing both ways through the tunnel were thence deduced:—

GASEOUS PRODUCTS and STEAM PER MILE PER MINUTE.

Trains per hour both ways.	Volume of Air, or Capacity of Tunnel, per mile. Volume.	Weight of Air at 62° Fahr.	Gaseous Products and Steam, per mile of Tunnel per minute. Volume at 62° Fahr.	Parts of volume of the Air.	Weight.	Parts of weight of the Air.
	Cubic feet.	lbs.	Cubic feet.		lbs.	
2	2,500,000	190,000	438	$\frac{1}{5708}$	24	$\frac{1}{7920}$
4	2,500,000	190,000	876	$\frac{1}{2854}$	48	$\frac{1}{3960}$
8	2,500,000	190,000	1,752	$\frac{1}{1427}$	96	$\frac{1}{1980}$
16	2,500,000	190,000	3,504	$\frac{1}{713}$	192	$\frac{1}{990}$
32	2,500,000	190,000	7,008	$\frac{1}{356}$	384	$\frac{1}{495}$

Digitized by Google

For forming an estimate of the quantity of ventilation that would be required on the dilution system, Dr. Letheby's measure of 15 volumes of carbonic acid in 10,000 volumes of air might be adopted as the limit of impurity. Then, the quantity of carbonic acid ejected by the locomotives, and pervading the air of the tunnel, was not to exceed the difference between the limiting quantity and the normal quantity in the atmosphere, or $(15 - 3{\cdot}5) = 11{\cdot}5$ volumes in 10,000 volumes of air. Now the proportion of the constituent carbonic acid in the gaseous products was one-sixth of the total volume; and it followed, by simple multiplication, that the limiting proportion of the whole of the gaseous products of combustion was $(11{\cdot}5 \times 6) = 69$, or, say, 70 volumes in 10,000. There were, in addition, $1\frac{1}{2}$ volume of steam from the engine, for every volume of gaseous products, or $(70 \times 1\frac{1}{2}) = 105$ volumes of steam in 10,000 of air; which made up a total of gaseous products and steam equivalent to $(70 + 105 =)$ 175 volumes in 10,000 volumes of air, as the limiting proportion, or 1 in 57.

To apply this ratio to the discharges of gas and steam, given in the preceding table:—it was there shown that, for two trains per hour, both ways, the discharge was equivalent to 1 volume in 5,708 of air per minute; or to $\frac{57}{5708}$ parts, or $\frac{1}{100}$th, of the limiting proportion. It would follow that, in order that the proportion of impurities might not exceed the permissible limit, the air of the tunnel should be entirely changed every hundred minutes. Correspondingly, the times in which the air of the tunnel should be entirely changed for various numbers of trains per hour, were—

VENTILATION THROUGH the ENTIRE SECTIONAL AREA of the TUNNEL.

Trains per hour both ways.	Discharge per minute in parts of the limiting proportion.	Time in which the Air of the Tunnel should be entirely changed.	Required Velocity of the current per mile of length of traverse.	
		Minutes.	Feet per minute.	Miles per hour.
2	$\frac{57}{5708}$, or $\frac{1}{100}$	100	52·8	0·6
4	$\frac{57}{2854}$, or $\frac{1}{50}$	50	105·6	1·2
8	$\frac{57}{1427}$, or $\frac{1}{25}$	25	211·2	2·4
16	$\frac{57}{713}$, or $\frac{1}{12{\cdot}5}$	12·5	422·4	4·8
32	$\frac{57}{356}$, or $\frac{1}{6{\cdot}25}$	6·25	844·8	9·6

The required velocity of the current for any given length of tunnel to be traversed was found by multiplying the tabular

Digitized by Google

velocity in either of the last two columns by the length of traverse; by this means the following table of velocities of current had been calculated—the current being exhausted from one end only of the tunnel:—

VELOCITY of VENTILATION THROUGH the ENTIRE SECTIONAL AREA of TUNNEL.

Trains per hour both ways.	Required Velocity of Current per mile of length.	Total Velocity of the Current, in miles per hour. Total Length of Tunnel, in miles.										
		¼	½	¾	1	2	4	6	8	10	15	20
Trains.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.
2	0·6	0·15	0·30	0·45	0·6	1·2	2·4	3·6	4·8	6·0	9·0	12·0
4	1·2	0·30	0·60	0·90	1·2	2·4	4·8	7·2	9·6	12·0	18·0	24·0
8	2·4	0·60	1·20	1·80	2·4	4·8	9·6	14·4	19·2	24·0	..	..
16	4·8	1·20	2·40	3·60	4·8	9·6	19·2	28·8	..	..	..	..
32	9·6	2·40	4·80	7·20	9·6	19·2	..	..	..	..	..	..

For the probable case of a tunnel under the English Channel, 20 miles long, traversed by only two trains per hour, both ways—that was, by one train each way per hour—the required velocity of a thorough draft was, by the table, 12 miles per hour. This calculation was corroborative of the estimate of Mr. Cowper, who considered that a velocity of current of 12½ miles per hour would suffice for the thorough ventilation of a tunnel 25 miles in length, traversed by trains at intervals of one hour each way. For the same length of tunnel and number of trains, the proportions on which the present calculations were based, would give a velocity of 15 miles per hour, which was in excess of Mr. Cowper's estimate; who probably had adopted a lower consumption of fuel than 35 lbs. per mile, as the basis of his estimate.

Mr. Morrison's formula assumed the following form for direct application:—

$$h = \frac{V^2 P L}{633{,}000\ A} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (a)$$

h = the head of pressure, in inches of water; V = the velocity of the current, in feet per second; P = the perimeter of the tunnel, in feet; L = the length of tunnel traversed, in feet; A = the sectional area of the tunnel, in square feet.

The value of the effective work done within the tunnel, in horse-

Digitized by Google

power, was expressed by the following formula, in which 1 inch of water was taken as equivalent to a pressure of 5·20 lbs. per square foot:—

$$HP. = \frac{V A h}{106} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (b)$$

in which HP. = the horse power; and, by substituting, in this formula, the value of h (formula a), and reducing,

$$HP. = \frac{V^3 P L}{67{,}000{,}000} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (c)$$

The engine-power required to effect the ventilation, by means of suitable machinery, might be taken at 2½ times the net horse-power for work done in the tunnel, to include an approximate allowance for the power consumed in the approaches to the ventilator. Then,

$$HP_1 = \frac{V^3 P L}{27{,}000{,}000} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (d)$$

in which HP_1 = the total indicator horse-power required. With this formula, the following table had been calculated:—

GROSS OR INDICATOR POWER REQUIRED for VENTILATION THROUGH the ENTIRE SECTIONAL AREA of the TUNNEL.

Trains per hour both ways.	INDICATOR HP. REQUIRED. Limit of Impurity:—15 volumes of carbonic acid in 10,000 volumes of air. Total length of Tunnel, in miles.										
	¼	½	¾	1	2	4	6	8	10	15	20
Trains.	HP.	HP.	HP.	HP.	HP.	HP.	HP.	HP.	HP.	HP.	HP.
2	..	..	..	..	0·2	3	15	48	118	625	1,900
4	..	..	..	0·1	0·5	24	120	388	946	5,000	15,140
8	..	..	0·27	0·8	12·0	192	960	3,104	7,568	..	..
16	..	0·4	2·20	6·4	96·0	1,536	7,680	..	..	..	..
32	0·2	3·3	16·00	51·0	768·0	12,288	..	..	..	..	..

These calculations revealed the principle that the power required for artificial ventilation increased as the fourth power of the length of tunnel, and as the cube of the number of trains. A tunnel 2 miles long, traversed by sixteen trains per hour both ways, might be ventilated with 96 indicator HP., whilst 768 HP. would be required to ventilate the same tunnel when traversed by thirty-two trains. Again, a tunnel 20 miles long, traversed by two trains and by four trains per hour, would require respectively 1,900 HP. and 15,000 HP. for its artificial ventilation.

Digitized by Google

The "separate system" of ventilation might be simply established by means of the horizontal brattice proposed by Mr. Barlow, having longitudinal openings, marked A, A, Fig. 3, with the additional interior brattice proposed by Mr. Longridge, but without any vertical diaphragms. The upper brattice would thus inclose a free driftway, which might be assumed to be 5½ feet high and 20 feet wide at the level of the brattice, and to have a clear sectional area of 60 square feet. Numerous openings in the upper brattice would allow the transmission of the gases from the interspace into the driftway, whence they might be exhausted at each end of the tunnel. The areas of the openings must be adjusted, so that the indraft at all points of the tunnel should be sufficient directly to withdraw the gases discharged into the interspace.

Since a continuous stream of discharged gases and steam from each train would be lodged above the brattices, and would be measured by 2½ square feet of section, the driftway would be capable of holding $(60 \div 2\frac{1}{2} =) 24$ streams of gases abreast, the discharge from twenty-four trains. Therefore, the average velocity of the exhaust current through the driftway should be such that the current might traverse the half-length of the tunnel in the same period of time in which twenty-four trains entered the tunnel. On this principle the average velocities given in the following table had been calculated. It would be observed that these average velocities were only one-fourteenth of those required for ventilation through the entire sectional area of the tunnel.

REQUIRED AVERAGE VELOCITY of ARTIFICIAL VENTILATION of the TUNNEL by BRATTICED DRIFTWAY.

Trains per hour both ways.	Required average Velocity of Current per mile of Tunnel.	Total average Velocity of the Current, in miles per hour. Total length of Tunnel, in miles.										
		¼	½	¾	1	2	4	6	8	10	15	20
Trains.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.	Miles per hour.
2	0·042	0·01	0·02	0·03	0·04	0·10	0·17	0·25	0·35	0·42	0·65	0·85
4	0·085	0·02	0·05	0·07	0·08	0·17	0·34	0·50	0·70	0·85	1·30	1·70
8	0·170	0·04	0·09	0·13	0·17	0·34	0·68	1·00	1·40	1·70	2·60	3·40
16	0·340	0·08	0·17	0·26	0·34	0·68	1·35	2·00	2·70	3·40	5·10	6·80
32	0·700	0·18	0·35	0·50	0·70	1·40	2·70	4·10	5·40	6·80	10·20	13·60

Digitized by Google

The average head or pull of the current was that due to the mean square of the uniformly accelerated velocities in the driftway from the middle towards each end; or to a velocity of 0·5775, when the maximum velocity was 1; or to the velocity 1·155 when the average velocity was 1. Then, 1·155 V was to be substituted for V in formula (*a*), to find the head; and 2 V, the terminal velocity, to be substituted for V in formula (*b*). Consequently, the second members of formulas (*c*) and (*d*) were to be multiplied by $(1{\cdot}155^2 \times 2 =)$ 2·67, and formula (*d*) became, by reduction,

$$HP_1 = \frac{\cdot V^3 P L}{10{,}000{,}000} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (e)$$

giving the total indicator HP. required.

TOTAL INDICATOR POWER REQUIRED for the ARTIFICIAL VENTILATION of TUNNELS by a BRATTICED DRIFTWAY, on the SEPARATE SYSTEM.

Trains per hour both ways.	INDICATOR HP. Two Traverses, each equal to half-length of Tunnel.										
	Total length of Tunnel, in miles.										
	¼	½	¾	1	2	4	6	8	10	15	20
Trains.	HP.	HP.	HP.	HP.	HP.	HP.	HP.	HP.	HP.	HP.	HP.
2	..	..	..	..	..	..	..	..	..	0·28	0·9
4	..	..	..	..	..	..	..	0·2	0·45	2·20	7·0
8	..	..	..	..	..	0·1	0·5	1·6	3·50	18·00	56·0
16	..	..	..	..	..	0·7	4·0	12·6	28·00	142·00	450·0
32	..	...	..	..	0·36	5·7	30·0	100·0	225·00	1,140·00	3,600·0

Here the power necessary to ventilate a tunnel, on the separate system, was an infinitesimal fraction of that which was required to ventilate on the dilution system acting through the entire sectional area of the tunnel. The quantities and powers tabulated were not put forward with any claim to exactness, yet conclusive evidence was afforded that the "separate system" of artificial ventilation—by brattices, pipes, or otherwise—was to be the method of the future. The separate system supplied a complete solution of the problem of the perfect and economical ventilation of the Metropolitan railway at one end of the scale of tunnels, and of the projected Channel Tunnel at the other extreme.

Digitized by Google

January 25, 1876.

GEORGE ROBERT STEPHENSON, President,
in the Chair.

The discussion upon the Paper, No. 1,443, "The Ventilation and Working of Railway Tunnels," by Mr. G. J. MORRISON, occupied the whole of the evening.

Digitized by Google

February 1, 1876.

GEORGE ROBERT STEPHENSON, President, in the Chair.

THE following Candidates were balloted for and duly elected:—Sir SAMUEL CANNING, DAVID CUNNINGHAM, THOMAS ROSS SALMOND, JOHN SOMES STORY, and JAMES PENMAN HUGH WALKER, as Members; JOHN ALLISON, WILLIAM BRENTNALL, WILLIAM JAMES CADETT, WILLIAM ALLAN CARTER, JOSEPH CARTMELL, BEN JAMES FISHER, HENRY JOHN HANDLEY, JOSEPH HARDWICK, GEORGE HAYCRAFT, GEORGE COLTHURST HEWITT, HERBERT GEORGE HUXLEY, Captain SAMUEL SWINTON JACOB, B.S.C., WILLIAM JOHNSTONE, ISAAC MATTHEWS JONES, WALTER ROBERTS JONES, Stud. Inst. C.E., THOMAS KIDD, Jun., ARTHUR HEMERY LE BRETON, Stud. Inst. C.E., GEORGE ARCHIBALD LUNDIE, ARTHUR MARSHALL, B.A., WILLIAM BESWICK MYERS, Stud. Inst. C.E., BOGHOS NUBAR, MALCOLM M'CULLOCH PATERSON, Major ROBERT CHARLES BOILEAU PEMBERTON, R.E., ROBERT PICKWELL, HENRY RICHARDS, Stud. Inst. C.E., JASON RIGBY, B.A., WILLIAM RUSSELL, Stud. Inst. C.E., HENRY WARING SAXTON, WILLIAM HENRY SCRIVEN, Stud. Inst. C.E., WILLIAM CHARLES STREET, BRENTON SYMONS, JOHN WEBSTER, and JOHN MERVYN WRENCH, Stud. Inst. C.E., as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. 8, of the Bye-Laws, had transferred WILLIAM HUNT from the class of Associate to that of Member.

Also that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:—RICHARD SYER ROBINSON, and GEORGE ATKINSON VAN SOMMER.

No. 1,454.—"Holyhead New Harbour." By HARRISON HAYTER, M. Inst. C.E.

THE new harbour at Holyhead being now completed, it is believed that a short account of this large undertaking may be interesting.

Between the years 1835 and 1847 the attention of Government

Digitized by Google

was directed to the importance of providing improved harbour accommodation on the coast of North Wales, in the interest of the packet service between England and Ireland, and, during the investigation that followed, the desirability of combining with any project a harbour of refuge received much consideration.

As might have been supposed from the importance of the subject, numerous inquiries, parliamentary and other, were made, various sites were proposed, and different schemes were suggested and reported upon.

From its situation Holyhead was doubtless the most natural place for a packet station; but during the early period of the inquiry an opinion prevailed that the railway access to Holyhead would be interrupted by the Menai Straits, which many considered would not be bridged to carry a railway. Hence, some advocated the construction of a harbour at Porthdynllaen, on the western shore of Carnarvonshire, and Ormes Bay, on its northern shore, received attention. Liverpool, too, was suggested as the place for the packet service to Ireland.

When, however, the bridging of the Menai Straits by the Chester and Holyhead Railway Company became no longer a matter of doubt, Holyhead was determined to be in every respect the most suitable place for the packet service, as well as for a harbour of refuge, and it was selected accordingly. Of the several schemes proposed, the plan suggested by the late Mr. Rendel, Past-President Inst. C.E., was ultimately accepted; and, in August 1845, he was requested by the Lords of the Treasury to furnish detailed plans and estimates of the new harbour, and he reported thereon on the 5th of December of that year.

In order to carry out the design a bill was introduced into Parliament, to empower the Commissioners of Her Majesty's Woods to purchase the necessary land, the Act receiving the royal assent on the 22nd of July, 1847.

The accepted plan consisted of a north breakwater, 5,360 feet in length from the coast line, and an east breakwater, about 2,000 feet in length, these two breakwaters inclosing between them an area of 267 acres of available water space, and of a packet pier, 1,500 feet long, within the inclosed area. The east breakwater was subsequently abandoned. It was to have commenced at Salt Island and to have been continued, in a northerly direction, to the Platters and Skinners Rocks (Plate 2). One of the chief objects of this breakwater was to cover these rocks, but their positions have, instead, been well marked by buoys. The packet pier was also abandoned. It was intended chiefly to provide improved accom-

Digitized by Google

modation for the Irish packet service, but subsequently it was determined to carry on the packet service in the old harbour, where jetties and works have been constructed for the purpose. The north breakwater alone has been retained, and the new harbour has become principally a harbour of refuge.

The harbour, as originally designed, was of a capacity much larger than many supposed would ever be required. It was found, however, as the works advanced, that, notwithstanding the abandonment of the new harbour as a packet station, which increased its capacity as a harbour of refuge, it was likely to prove too small even for refuge purposes. The breakwater, as the rubble mound or lower portion advanced, afforded considerable shelter, and the harbour thereby formed was much resorted to by shipping; and when the breakwater was approaching near to the point originally intended for its termination, the harbour was so frequently filled by wind-bound vessels that the then harbour-master, Commander Skinner, wrote to the Lords of the Admiralty, on the 2nd of February, 1854, urging its enlargement, and stating that "if any serious complaint is made against the harbour, I feel convinced that it will be for deficiency of space; and as the time is not yet gone by for remedying this anticipated want, I have ventured to address their Lordships on the subject." The Lords of the Admiralty therefore decided to lengthen the breakwater by 2,000 feet, and afterwards by 500 feet more, making its total length 7,860 feet from the shore. This extension more than doubled the capacity of the harbour for refuge purposes, for it sheltered a roadstead of 400 acres of deep water. The direction of the main line of the breakwater was almost due east; but it was decided that the extension should take a north-easterly direction, to shelter a larger area of roadstead, and to enable vessels more easily to enter the harbour.

The north breakwater consists of a mound of rubble stone or 'pierre perdue,' upon which is erected a substantial stone superstructure, the end of the breakwater being terminated by a head, on which there is a lighthouse.

The stone was obtained from an adjoining hill known as Holyhead Mountain. The quarries were opened at the foot of the mountain nearest the breakwater, being rather less than 1 mile distant from the commencement of the work. The stone is quartz rock, and it is fortunate that material of such a suitable quality existed so near at hand.

Before, however, any stone could be put into the sea, it was necessary to construct nearly 2½ miles of single line of railway to

Digitized by Google

convey it; and in the same contract was included the building of an outer sea wall 864 feet long, and of an inner wharf wall 924 feet long at Soldiers Point (for the purpose of inclosing the rocks projecting into the sea where the north breakwater joins the land), a pitching of rough stone where the east breakwater was to have been united with the coast, and the blasting of a quantity of rock to the level of low water in front of the inner wharf wall. The money expended on these preliminary works amounted to £92,000.

The operations of quarrying the stone at the Holyhead Mountain were some of the largest and most interesting that have ever been undertaken. At the outset the quarrying operations were conducted in the usual way, by drilling holes and firing small shots, and although many men were employed, this system proved unequal to the great demand. The firing had to take place at stated intervals two or three times a day, and the men, horses, and large plant had to be removed out of the way to a place of safety. Time was wasted, and the process was dangerous, but it was continued for a year or two until the contractors introduced blasting on a much larger scale, by sinking shafts and driving headings or driftways, in which large quantities of powder were placed and fired by the galvanic battery.

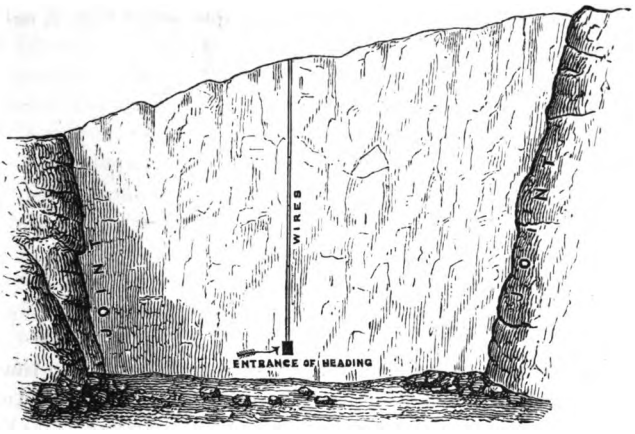
The first large mines were in shafts about 6 feet by 4 feet, sunk from the top, and of varying depths according to the height of the face; but when the quarries had been more opened and the face got very high, sometimes the top was only prepared for blasting by shafts, and the bottom by headings of about the same size as the shafts, or somewhat less. Ultimately, headings were preferred to shafts, and were adopted whenever practicable. They proved more convenient, as the men could work in front instead of at their feet, they did not get wet from rain, and the ventilation was better. Headings were also less dangerous as the tamping was less liable to be blown out, and stones did not fall into them as was sometimes the case in shafts. On the other hand, shafts had the advantage over headings in being more easily tamped, and in requiring smaller charges of powder, as the rock to be displaced was weakened from top to bottom by the excavation.

From the novelty of the procedure it was at the outset difficult to calculate the proper quantity of powder. The charges depended very much on the relative position, to the adjoining rock, of the stone which it was contemplated to remove by the shaft or heading, on the position of the joints, and on the hardness or compactness of the stone at different parts of the quarries. In mine Fig. 1, which was fired in March 1856, upwards of 60,000 tons of rock were

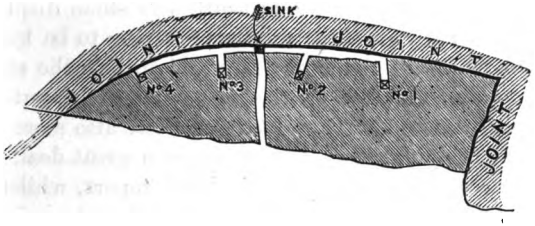
Digitized by Google

removed by a charge of 13,000 lbs. of powder, or nearly 5 tons of rock to 1 lb. of powder, whilst in other cases rock would be removed only at the rate of 2 or 2½ tons to 1 lb. of powder. On the average 4 tons of rock were blasted by 1 lb. of powder. After a short time, by studying the varying circumstances, the quantity

FIG. 1.



ELEVATION.



PLAN.

Height of face, 110 feet. Length of face, 140 feet.
Length of heading, 89 feet. Grip of heading, 35 feet.
Depth of sink, 13 feet 6 inches, being 3 feet below the level of quarry.
Length of chambers—No. 1, 12 feet 6 inches; No. 2, 12 feet; No. 3, 9 feet; No. 4, 2 feet 6 inches; total, 36 feet.
Charges—No. 1, 4,500 lbs.; No. 2, 4,000 lbs.; No. 3, 3,000 lbs.; No. 4, 1,500 lbs.; total, 13,000 lbs.
Lines of least resistance—No. 1, 23 feet 6 inches; No. 2, 24 feet; No. 3, 25 feet; No. 4, 18 feet.
Produce, upwards of 60,000 tons.

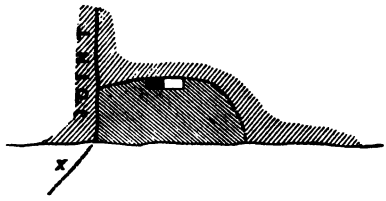
of powder that should be used to obtain the best result was reduced to something like rule. It was found that, by a proper apportionment, not only were the blasts rendered more certain in action and less dangerous, but the stone was better broken up into the sizes suitable for the breakwater. In driving the mines advantage was taken as far as practicable of the joints of the rock. The mine just

Digitized by Google

referred to was favourable in this respect. The chambers containing the powder were taken down to the level of 3 feet below the bottom of the quarry. It was found desirable to do this, although a greater quantity of powder was thereby rendered necessary, as it assisted in disturbing the stone to the bottom of the quarry. Notwithstanding, some stone had always to be removed afterwards by small shots to maintain the floor of the quarry at a uniform level.

One of the worst cases to deal with was mine Fig. 2, called a

FIG. 2.



PLAN OF ROOTER-OUT.

Depth of shaft, 44 feet. Charge, 900 lbs.
Line of least resistance, 21 feet. Produce, 2,000 tons.

'rooter-out,' where there was a joint on one side only, so that the rock had principally to be torn away from the solid mass. In this case—and there were many similar cases—a charge of 900 lbs. of powder brought down only 2,000 tons of rock, or 2¼ tons per lb. of powder. Besides this small result, the stone displaced in such mines was usually in large masses requiring to be broken up by small shots, whilst in the more favourable blasts the stone was broken up into sizes suitable for the most part to be put at once into the wagons. These unfavourable mines were also more dangerous when fired; the stone usually flew about a great deal, and the explosion was always accompanied by a loud report, whilst in the favourable mines there was but little noise, the stone falling or sliding down quietly. As an instance it may be recorded that when mine Fig. 6 was fired, a goat grazing on the top of the mass to be dislodged, came down with the mass unhurt.

The two first mines described may be regarded as types of the best and the worst, excepting that if the 'rooter-out' happened to be at a re-entering angle, as shown by the dotted line, Fig. 2, the case would be even still worse. It was in an attempt to fire a mine of this kind, Fig. 3—one of the first that was tried—that a serious accident happened, which it will be instructive to record. The mine consisted of two separate shafts X and Y. These were to have been fired simultaneously, but owing to the fracture of one of the battery wires, the shaft Y did not explode. The result

Digitized by Google

was that, owing to the charge in X being insufficient to remove the rock, the tamping in that shaft blew out, and was showered amongst a group of spectators who came to witness the explo-

FIG. 3.

PLAN.

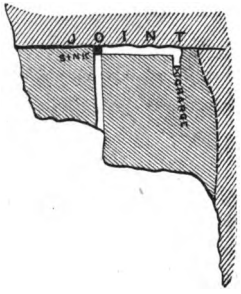
Mine X.
Depth of shaft, 43 feet.
Line of least resistance, 28 feet.
Charge, 2,600 lbs.
Assumed produce, 7,000 tons.

Mine Y.
Depth of shaft, 56 feet.
Line of least resistance, 30 feet.
Charge, 2,000 lbs.
Assumed produce, 8,000 tons.

sion, amongst whom was Captain Hutchinson, of the Royal Engineers, who was so severely wounded that he died a few hours afterwards. Captain Hutchinson was interested in and had aided in planning the mine. He had had large experience in blasting, and was well known as having been engaged in the operations connected with the large blast for the South-Eastern railway at the Round Down Cliff, near Dover, in 1843.

Figs. 4, 5, 6 and 7 show other examples of mines at Holyhead,

FIG. 4.



PLAN.

Height of face, 110 feet.
Length of heading, 25 feet.
Grip of heading, 25 feet.
Depth of sink, 20 feet.
Line of least resistance, 36 feet.
Charge, 4,200 lbs.
Produce, 12,000 tons.

the particulars being given with each. Generally, the charges varied from 600 lbs. to 21,000 lbs. of powder, the latter quantity having been actually exploded in mine Fig. 7, fired on the 21st of

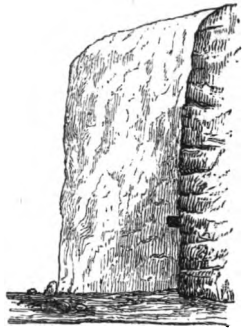
Digitized by Google

May, 1857. This mine took about nine months to prepare, and it was stated dislodged 130,000 tons of stone.

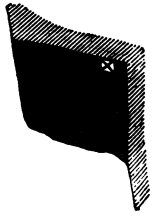
The strength of the blasting powder was tested by the power of 1 ounce to throw a ball of 68 lbs. to a distance of 180 feet, from a small mortar, elevated at an angle of 45°. The powder was delivered at Holyhead in small barrels of 50 lbs. each, which were stored in strong magazines, and it was delivered at a cost of between £50 and £55 a ton.

In tamping the headings, the powder was often built in for a few feet with a dry rubble wall, and the remainder of the galleries rammed with clay, obtained from a decomposed porphyry dyke

FIG. 5.



ELEVATION.



PLAN.

Height of face, 90 feet.
Line of least resistance, 28 feet.

Charge, 1,700 lbs.
Produce, 2,700 tons.

in the quarries. The shafts were more readily tamped, with quarry débris, stones, and clay thrown in and rammed. Occasionally, especially at the outset, a space was left round the charge, but it is believed that this was of little use.

Sir John Burgoyne, in his Treatise on the Blasting and Quarrying of Stone, gives as a rule for small shots that the charge of powder in pounds should be equal to $\frac{1}{3\frac{1}{2}}$ of the cube of the line of least resistance in feet. This quantity is not sufficient for the

Digitized by Google

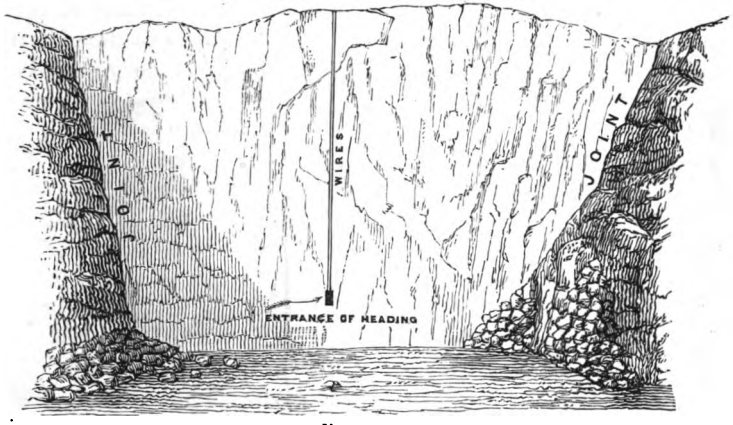
hard rock at Holyhead, and the result of experience determined the following approximate rules :—

For ordinary shafts, charge in lbs. = $\frac{1}{13}$ to $\frac{1}{23}$ the cube of the line of least resistance in feet.

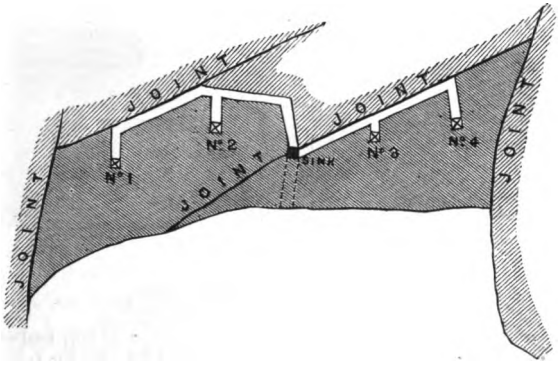
For ordinary headings, charge in lbs. = $\frac{1}{12}$ the cube of the line of least resistance in feet.

For 'rooters-out,' charge in lbs. = $\frac{1}{10}$ the cube of the line of least resistance in feet.

FIG. 6.



ELEVATION.



PLAN.

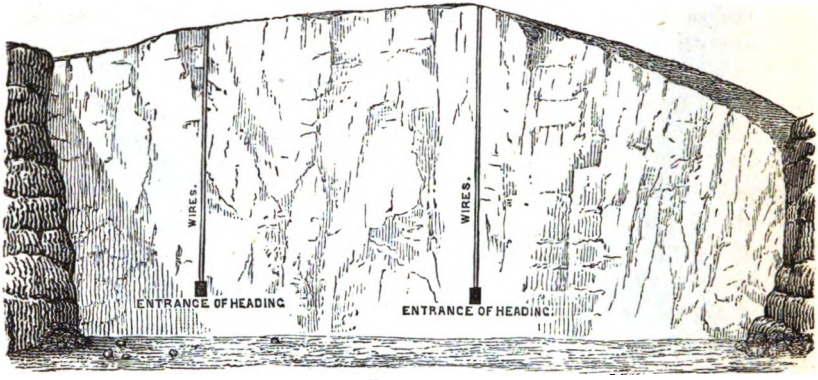
Height of face, 115 feet. Length of face, 210 feet.
Length of heading, 125 feet. Grip of heading, 33 feet.
Depth of sink, 23 feet, being 3 feet below level of quarry.
Length of chambers—No. 1, 12 feet; No. 2, 12 feet; No. 3, 6 feet; No. 4, 15 feet; total, 45 feet.
Charges—No. 1, 4,200 lbs.; No. 2, 4,500 lbs.; No. 3, 2,300 lbs.; No. 4, 5,000 lbs.; total, 16,000 lbs.
Line of least resistance, average 23 feet.
Produce, 120,000 tons.

It is evident, however, that in blasts like those at Holyhead these rules would be more or less arbitrary, and subject to many

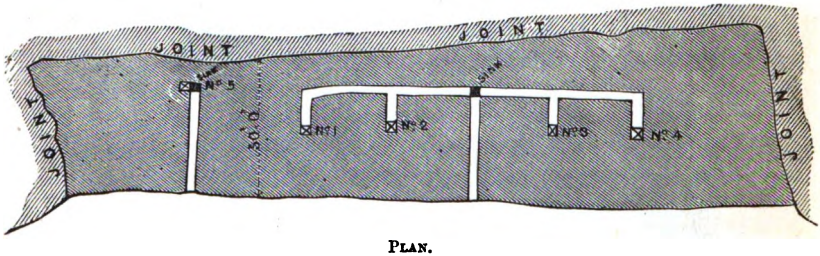
Digitized by Google

variations. They are based on the line of least resistance, as this has been the general recognised standard for determining the quantity of powder. But in the quarries at Holyhead the height of the face differed materially, and the position and nature of the joints, the form of the rock, as well as its hardness, were very variable. Hence, as a check upon these general rules, the quantity of rock which it was expected would be displaced, and which could be ascertained approximately, was measured, and the powder was

FIG. 7.



ELEVATION.



PLAN.

Height of face, 120 feet. Length of face, 250 feet.
Length of heading, 120 feet. Grip of heading, 40 feet.
Depth of sink, 15 feet, being 3 feet below the level of quarry.
Length of chambers—No. 1, 12 feet; No. 2, 12 feet; No. 3, 12 feet; No. 4, 12 feet; total 48 feet.
Charges—No. 1, 5,000 lbs.; No. 2, 4,000 lbs.; No. 3, 4,000 lbs.; No. 4, 5,000 lbs.; No. 5, 3,000 lbs.; total, 21,000 lbs.
Line of least resistance, average 23 feet.
Produce, 130,000 tons.

apportioned to the quantity of rock to be removed, having regard to the varying conditions and circumstances.

The cost of quarrying the rock, including driving, powder, and sundries, was 4½*d.* a ton, and the cost of filling into wagons, including blasting the large stones, was about the same. These, how-

Digitized by Google

ever, were the lowest rates for quarrying and filling, as at the time they were taken the maximum output had been attained. The details of these prices are given in the Appendix, Table III.; and the amount of stone deposited in each successive year in Table IV. The cost of driving the headings ranged from 10*s.* to 25*s.* per lineal foot, out of which the miners had to pay on an average about 2*s.* for the powder, fuses, &c. The average length of heading driven was 5 feet per week with four men.

The rubble mound is of great size; the average depth of water at low-water spring tides being 40 feet, and the greatest depth 55 feet, the variation of the tide at ordinary spring tides being 17 feet, and at equinoctial spring tides 20 feet. The inclination of the foreshore, or slope from low water, to the superstructure is generally about 12 to 1, and this inclination continues to 1 foot or 2 feet below low-water mark, when the mound assumes a slope of 5 to 1 to about 10 feet or 12 feet below low-water mark, and about 2 to 1 from that point to the bottom. On the harbour side the slope of the mound is about $1\frac{1}{4}$ to 1. At the level of low water the mound is nowhere less in width than 250 feet, and in 50 feet depth of water it is about 450 feet wide at the base. It contains altogether about 7,000,000 tons of stone. The weight of the stone in mass is about 1 ton to $13\frac{1}{2}$ cubic feet, but in the breakwater 1 ton of the stone occupies on an average somewhat less than 20 cubic feet of space.

The stone was deposited from wagons running over a temporary wooden staging, Plate 3. This staging was constructed with five lines of railway, all in communication with the lines to the quarries, and all laid to the wide gauge of 7 feet. The roadway platform carrying the rails was supported by piles of double balks stiffened by A piles in several of the bays, and they were sunk in place by boxes filled with stone fixed to the lower part of the pile. The piles were not driven, but placed on the ground, and when in their situation they were surrounded with stone tipped from the wagons. The width of this staging was 150 feet at the level of the rails, which were 20 feet above high-water mark, being placed at this elevation so as to remove the roadway platform, to some extent, from the influence of the waves. The average cost of one bay 30 feet long, of the staging erected in place, in 50 feet depth of water, at low water, was somewhat less than £600, details of which are given in Table V. of the Appendix.

The tipping wagons (Plate 3), designed by the late Mr. G. C. Dobson, M. Inst. C.E., were for the most part of iron, and were constructed to hold each from 8 tons to 10 tons of stone, the tipping arrangement consisting of a movable shoot, which held

Digitized by Google

the stone, and which was of the length of the wagon. This shoot was hung on strong wrought-iron pins to the body of the wagon, and was kept in place by a trigger. When the wagon was to be emptied the trigger was released, and the shoot fell down and discharged its contents into the sea between the rails; when emptied the shoot, which was counterbalanced, returned into place, the trigger was locked, and the wagon sent back to the quarry to be reloaded. About two hundred and fifty of these wagons were employed on the works, and during the time the operations were most active about 4,000 tons of stone were deposited daily in the sea, the greatest quantity ever tipped in one day being 5,220 tons; in one week, 26,164 tons; in one month, 109,707 tons; and in one year, 1,066,918 tons. (Appendix, Table IV.)

From the two inner roads of the staging on the harbour side, the stone was deposited to the level of about high-water neap tides, and being protected from the influence of the sea by the stone dropped from the outer roads, which were kept higher and in advance, the stone on the harbour side remained comparatively undisturbed, and formed for itself the slope towards the harbour of about $1\frac{1}{4}$ to 1. From the three outer roads on the sea side, stone was deposited until it reached the top of the staging; it formed the mass of the breakwater on the sea side, including the foreshore and the stone from the foreshore to the bottom. This foreshore and the seaward mass beyond it were formed as follows. These three outer roads being filled up, the first storm washed down the stone seaward to a greater or less extent, depending on the violence and continuance of the disturbance. These roads were then refilled, to be again washed down; and so the process continued for several times, until the sea shaped the mound to the form in which it remains, and which is shown on the section of the breakwater (Plate 3). The stone in the mound consists of an admixture of large and small pieces, the small pieces filling up the interstices, whereby a compact mass has been obtained.

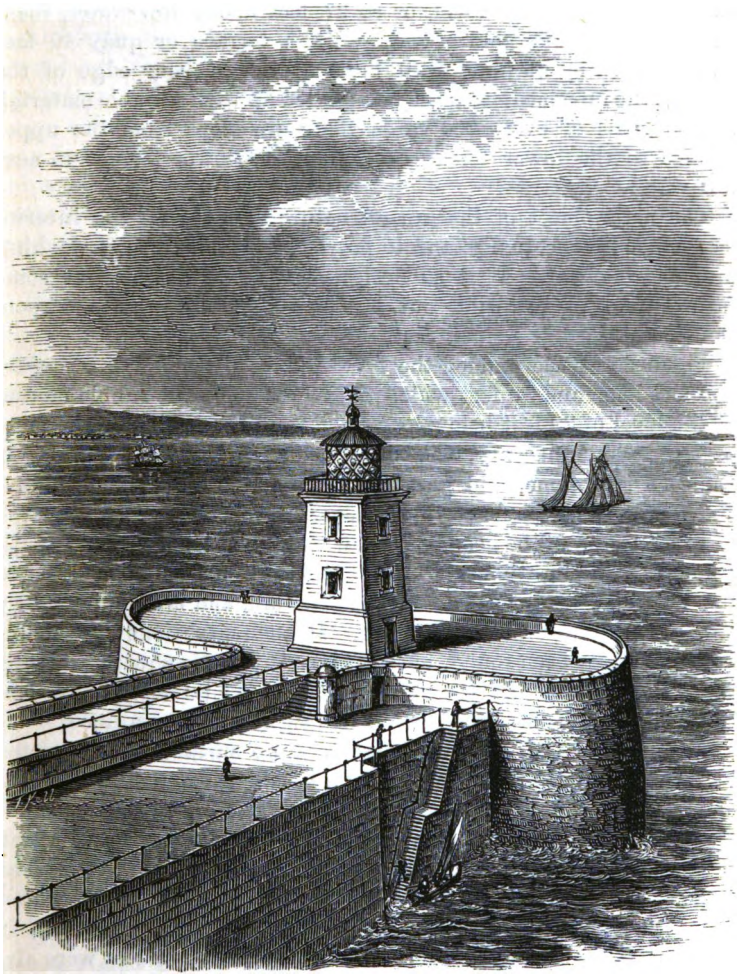
During the process of forming the mound, the staging at the end of the work was frequently washed away by gales before it was well surrounded; but it was considered by the contractors better to adopt the staging described than to be at the cost of one of a more permanent and expensive character, especially as the timber removed during gales could, as a rule, be recovered.

The rubble mound having been formed, and consolidated by the continual action of the sea, the superstructure was erected. This consists of a solid wall of massive masonry, built principally of quartz-rock stone, from the Holyhead Mountain quarries; the

Digitized by Google

plinths, cornices, parapets, paving, copings, and other ashlar work, being of Anglesea limestone. Many of the quartz-rock stones are of very large size, some weighing upwards of 15 tons,

Fig. 8.



Head of the Holyhead Breakwater.

and the work is set in lias-lime mortar. The foundations of this wall are laid at the level of low water, for which purpose the loose stone of the mound had to be excavated. The wall was built, as

Digitized by Google

near as circumstances would admit, to the inner edge of the stone deposit, in order to allow as long a foreshore on the sea side as could be obtained. This solid wall is carried up to a height of 38 feet 9 inches above low water to the level of a handsome promenade, which is surmounted, on the sea side, by a massive parapet. At a lower level, or at 27 feet above low water, there is, on the harbour side of this wall, a terrace or quay 40 feet wide, formed by an inner wall built at the harbour edge of the deposit, the intermediate space being filled up with suitable material. At intervals of every 200 yards there are steps from the upper terrace to the lower terrace, and from the lower terrace to near low water.

The main object of the superstructure is to shelter the interior harbour more effectually, and to prevent the loose deposit washing into the harbour. It is so designed that, if desirable at some future time, by throwing out jetties, convenient wharfage room can be obtained at a small cost.

The head at the end of the breakwater is a massive structure 150 feet long, and 50 feet wide. It is founded on the rubble mound at the level of 20 feet below low water, and it is built for the most part of ashlar masonry, the stone below low water being partly Runcorn sandstone, and partly Anglesea limestone set dry, and above low water Anglesea limestone set in mortar.

The masonry of the head below low water was built by divers with helmets. The lighthouse, which is 70 feet high from high water to the centre of the light, is a stone structure, and is illuminated by a dioptric light of the third order. In such situations lighthouses have generally been round, but this has been made square, whereby the living rooms, and the accommodation are rendered more commodious, and the structure is not less sightly in appearance.

The shore of the harbour being rock, no suitable place existed for beaching vessels. Accordingly a beaching ground was formed on the southern margin of the harbour (Plate 2), by tipping small stone débris, a large quantity of which was obtained in quarrying the stone for the rubble mound of the north breakwater. The slope of the beaching ground was made 1 in 10 down to low water. Altogether upwards of 300,000 tons of quarry débris were used in forming the beaching ground. Suitable landing places were also made at convenient spots along the shore.

The cost of the north breakwater and works connected therewith, including land, has been about £1,285,000, and its length from the coast line to the end of the head being 7,860 feet, it follows that the cost per lineal foot, including superstructure and

Digitized by Google

head, has been about £163 10*s*. The cost of the stone deposited in the rubble mound was 2*s*. 3*d*. a ton for the first portion of the breakwater, and 2*s*. 7*d*. a ton for the last 2,500 lineal feet. The cost of the superstructure alone, excluding the head, was £36 a lineal foot. Further details as to prices are given in the Appendix, Table VI.

Although the expenditure to secure a harbour of refuge has been large, the value of the harbour is beyond doubt, and it has become an important national undertaking. It is used to a very large extent, and the protection it affords to life and property may be gathered when it is stated that on an average about 3,500 ships seek refuge in the harbour in the course of a year. Few harbours possess greater facilities of ingress and egress, and the holding ground is very good. The harbour is quite free to all vessels which resort to it for shelter.

During the progress of the works changes have taken place in the administration and management. Up to the end of the year 1862 the harbour was under the control of the Admiralty. The passing of "The Harbours Transfer Act, 1862," placed it from the 1st of January, 1863, under the control of the Board of Trade, the Harbour Department of which has, since early in the year 1867, been under the charge of Mr. C. Cecil Trevor. The late Mr. James Meadows Rendel was Engineer-in-Chief from the commencement of the work until his death at the end of 1856, when Mr., now Sir John, Hawkshaw was appointed Engineer-in-Chief, who subsequently carried out the works, and brought them to a successful completion in 1873, and on the 19th of August of that year the Prince of Wales visited the works, and formally declared the harbour completed. The late Mr. George C. Dobson was the Resident Engineer. Mr. George Fosbery Lyster, M. Inst. C.E., now Chief Engineer to the Liverpool Docks, was Assistant Engineer from the commencement of the works to 1853, and the Author from 1853 to 1857; since which he has been associated with the harbour under Sir John Hawkshaw. Mr. Thomas Harris was Assistant Engineer from 1857 to 1861. Messrs. J. and C. Rigby were the Contractors.

The communication is accompanied by a series of diagrams, from which Plates 2 and 3 have been compiled and the woodcuts have been engraved.

Digitized by Google

APPENDIX.

TABLE I.—AREA of HARBOUR SHELTERED by the NORTH BREAKWATER.

	Acres.	Acres.
Area of Harbour within the Platters and Skinners Rocks—		
Area above 5 fathoms depth of water at low water	130	
Between 4 and 5 fathoms „ „ „ „	65	
„ 3 and 4 „ „ „ „ „	30	
„ 2 and 3 „ „ „ „ „	42	
Total available area, or area above 2 fathoms depth of water at low water	..	267
Area of Roadstead outside the Platters and Skinners Rocks—		
Area above 5 fathoms depth of water at low water	200	
Between 3 and 5 fathoms „ „ „ „	150	
Under 3 fathoms depth of water at low water, but all available	50	
Total available area of roadstead	..	400
Total area of harbour and roadstead	..	667

TABLE II.—COST, &c., of DRILLING HOLES for SMALL SHOTS.

	s.	d.
The average price for drilling in quarries with 1-inch round iron, 1¼-inch gauge, per lineal foot	1	1¼
No. of drills sharpened 11		
Consumption of iron . . . . . ⅜ lb.		
„ of steel . . . . . ⅛ lb.		
Average price for drilling in quarries with 1¼-inch round iron, 1¼ inch gauge, per lineal foot	1	4
No. of drills sharpened 14		
Consumption of iron . . . . . ⅜ lb.		
„ of steel . . . . . ⅛ lb.		

The above are for holes 3 feet to 5 feet deep, and the average work done over the whole quarries, in drilling the holes for the small shots, was 14 inches per hour by three men using 1¼-inch drills.

Digitized by Google

TABLE III.—ABSTRACT from WEEKLY STATEMENTS of the COST of QUARRYING and FILLING 1 TON of STONE taken in the Year 1855.

	Pence per Ton.	
Quarrying.		
Powder for headings and shafts	2·80	
Driving „ „	1·74	
Superintendence	0·04	
Total cost of quarrying	4·58	= 4·58
Filling.		
Wages of fillers and gangers	2·11	
Quarrymen blasting large stones	0·78	
Powder used by quarrymen	0·12	
Wages of carpenters, smiths, strikers, point-boys, tool-boys, breaksmen, drivers of horses, platelayers, and general labourers	1·27	
Superintendence	0·11	
Cost of filling wagons	4·39	= 4·39
Total cost of stone, per ton		8·97

TABLE IV.—PROGRESS of the BREAKWATER and the USE made of the NEW HARBOUR by SHIPPING.

	Stone deposited in each year.	Extreme extension of Breakwater Stage, and deposit each year.	Length of Superstructure built to the full height each year.	Number of Vessels entering the New Harbour each year.
	Tons.	Feet.	Feet.	Vessels.
Year ending March 1850[1]	142,463	370	..	..
„ 1851	484,396	1,093	..	182
„ 1852	597,077	717	..	201
„ 1853	864,440	775	..	669
„ 1854	1,013,120	1,190	..	1,801
„ 1855	888,018	879	..	1,760
„ 1856	1,066,918	1,185	..	2,001
„ 1857	899,018	641	..	2,886
„ 1858	476,535	410	..	2,968
„ 1859	153,231	Stone for superstructure and completing Breakwater.	..	3,025
„ 1860	128,389		1,802	3,100
„ 1861	106,533		2,026	3,498
„ 1862	119,534		1,480	3,607
„ 1863[2]	51,190		1,351	3,572
Total 14¼ years .	6,990,862	7,260	6,659[3]	29,270

5,220 tons is the greatest quantity of stone deposited in any one day, viz., on August 7th, 1855.

26,164 tons is the greatest quantity of stone deposited in any one week, viz., from August 13th to 18th (inclusive), 1855.

109,707 tons is the greatest quantity of stone deposited in any one month, viz., from July 16th to August 15th, 1855.

1,066,918 tons is the greatest quantity of stone deposited in any one year, viz., from March 31st, 1855, to March 31st, 1856.

[1] From January 1st, 1849.
[2] After 1863 very little stone was deposited.
[3] The rest of the superstructure and the head were built since 1863.

Digitized by Google

TABLE V.—COST of ONE BAY of the NORTH BREAKWATER STAGING ERECTED in PLACE in 50 FEET DEPTH of WATER at LOW WATER.

	£.	s.	d.	£.	s.	d.
3,700 cubic feet of Quebec yellow pine at 2s. 2d.	400	16	8			
4 tons 10 cwt. of manufactured wrought ironwork at £22	99	0	0			
2 tons 10 cwt. of rails at £10.	25	0	0			
				524	16	8
Labour in preparing timber and erecting stage, including cost of fixing ironwork, &c., 3,700 cubic feet, at 4d.		..		61	13	4
				586	10	0

TABLE VI.—PRICES of the WORK of the NORTH BREAKWATER.

1. *Rubble Mound.*

	s.	d.	
Cost of the stone deposited in place in the rubble mound from the commencement of the breakwater to a point 2,500 feet from the end	2	3	per ton.
Cost of ditto ditto for the last 2,500 feet of breakwater	2	7	„

2. *Cost of the Superstructure £36 per lineal foot: the following being the principal rates.*

	s.	d.	
Rubble masonry of mountain stone below the level of 20 feet 9 inches above zero, including excavation	15	0	per cubic yard.
Rubble masonry of mountain stone above the level of 20 feet 9 inches above zero.	11	6	„ „
Ashlar of Anglesea limestone	2	6	per cubic foot.

3. *Prices for the North Breakwater Head.*

	s.	d.	
Levelling rubble mound to receive footings of walls	1	1	per superficial foot.
Runcorn sandstone ashlar masonry below zero	2	11	per cubic foot.
Anglesea limestone ashlar masonry below zero	3	5½	„ „
Rubble masonry of mountain stone above zero, set in lias lime mortar	15	9	per cubic yard.
Ditto ditto, in Portland cement mortar	18	1½	„ „
Dressed Anglesea limestone ashlar above zero	2	3½	per cubic foot.
Dressed Runcorn limestone ashlar ditto	1	9	„ „
Anglesea limestone ashlar in lighthouse, set in Portland cement mortar	4	6	„ „

4. *Beaching Ground.*

The cost of the quarry débris deposited on the beaching ground was 11*d.* per ton, including levelling rock on the shore margin.

The weight of 1 cubic yard of quarry débris is 22 cwt.

[Mr. HAYTER

Digitized by Google

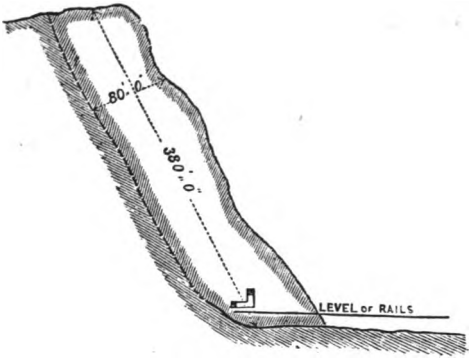
Mr. Hayter said it occurred to him that the description he had given of the mines might perhaps be better understood by a short explanation. His intention in the first instance was to describe a mine of the most favourable character, and for that purpose he had selected as an example the mine Fig. 1 referred to in the Paper. Next he wished to describe a mine of the most unfavourable character, and he selected the mine Fig. 2. Intermediate to these he had described five other mines, the seven selected and shown in sketches forming good types of all that had been fired at Holyhead. Altogether about one thousand mines had been fired, and about 7,000,000 tons of stone had been tipped into the sea. It therefore followed that, on an average, each mine produced about 7,000 tons of stone. During the process of sinking the shafts and driving the headings no water had been met with, a circumstance which much facilitated the operations of the contractor. The battery used in firing the mines was Groves's wet voltaic battery. Of course the number of cells in the battery varied according to circumstances. In mine No. 7 forty-six cells were used. That was one of the largest and most important mines that had ever been fired in connection with the operations of Civil Engineers.

Before the works at Holyhead were begun the celebrated mine at the Round Down Cliff, Dover, had been made and fired in 1843, under the direction of the late Sir William Cubitt, assisted by the late Captain Hutchinson, R.E., to facilitate the construction of the South-Eastern railway at that spot. That mine had an important bearing on the operations at Holyhead, inasmuch as the experience derived there determined to a great extent the system followed at Holyhead, where also the contractors had at the outset the aid of Captain Hutchinson, who unfortunately was killed at the Holyhead quarries as described in the Paper. The mass of chalk that had to be removed at the Round Down Cliff was about 360 feet long, 380 feet deep, and 80 feet in width, as shown in the following Fig. 8. The first operation was driving a heading; then three shafts, *a*, *b*, and *c*, were sunk. Three short galleries were next driven, and then three chambers, *d*, *e*, and *f*, for the powder. The quantity of powder used was determined by taking as a rule the charges in pounds equal to $\frac{1}{32}$ of the cube of the lines of least resistance in feet, instead of $\frac{1}{10}$ or $\frac{1}{12}$, as had often been necessary to blast the hard quartz rock at Holyhead. In chamber *d* accordingly the charge was 5,500 lbs.; in chamber *e*, 7,500 lbs.; and in chamber *f*, 5,500 lbs.; making altogether 18,500 lbs., or about 8¼ tons. The produce of the mine was 400,000 cubic

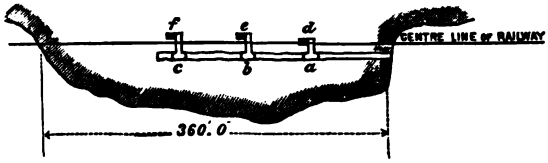
Digitized by Google

yards of chalk, equivalent to about 700,000 tons. In the largest mine at Holyhead, that shown on Fig. 7, an expenditure of 9½ tons of powder was required to remove 130,000 tons of hard quartz rock.

FIG. 9.



SECTION.



PLAN.

FIG. 10.

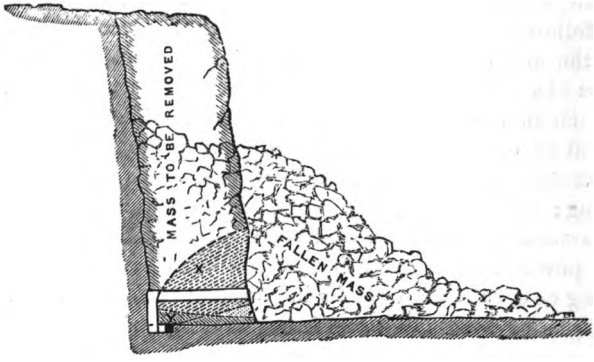


Fig. 9 represented the mine at the Round Dow Cliff at Dover before it was fired.

After an explosion at Holyhead the mass, in a favourable mine,

Digitized by Google

would fall down in position somewhat as indicated in Fig. 10, and it was well broken up. In an explosion a conical piece, X, was probably blown out in the first instance, this being immediately followed by the falling down of the general mass. A bottom piece, Y, usually remained after the explosion, which gave some trouble, as it had to be removed by small shots in drilled holes to maintain the bottom of the quarry at a uniform level. In unfavourable mines the mass was much scattered about after explosion, in large unbroken pieces, sometimes blocking up for days the roads near the quarry face; occasionally isolated stones would be thrown to distances of ½ mile.

Mr. LOVELL said, having had charge of the blasting operations at Holyhead for two or three years, he had much pleasure in bearing testimony to the accuracy of the details furnished in the Paper. The work was placed under his control shortly after the death of Captain Hutchinson. He believed that lamentable accident was owing to the charge of powder having been placed directly at the bottom of the shaft, and, not being able to overcome the resistance offered by the rock, blowing the tamping into the air. Had the mine been carried at a right angle from the bottom of shaft towards the face of quarry, and the powder placed there, he believed the rock would have been dislodged. The practice of giving each mine two or three right-angled bends before the powder was chambered was afterwards adopted; and during the time he was in charge of the operations he did not remember an accident.

With reference to the conveyance of the stone to the breakwater, he might mention that the wagons, after being loaded, moved from the face of quarry by their own gravity, in charge of breaksmen, passing over a weighbridge where the load was registered, and then down the main line by an easy incline to the shore end of the breakwater; they were afterwards cut off in sets of three or four, and pushed out by small tank locomotives along the staging to tip, and then returned to a siding, from whence they were taken up in sets of twelve or fifteen to quarry sidings, and from there distributed by horses to the face to be again loaded.

Mr. C. RIGBY said, in reference to the quality of the powder, on the first trials they used that which was ordinarily employed for such purposes, namely, blasting powder, which Sir John Burgoyne had greatly eulogised in the work which had been referred to in the Paper. Various experiments were made according to the recommendations suggested by Sir John Burgoyne, such as mixing sawdust or other foreign matters with the powder to allow of the

Digitized by Google

expansion of the gases generated on ignition; but those recommendations had been proved by experience to be fallacious. In the end the powder which was found most economical, and productive of the best results, was cannon powder. Powder from all makers was tried for three or four months, and as that which produced the most satisfactory results in every respect was supplied by Curtis and Harvey, their powder was invariably used until the completion of the works, upwards of 1,000 tons having been used in the mining operations. The Author had made an omission in explaining the form in which the headings were driven. The line of least resistance was taken. The heading was first driven, of the size named by the Author, to the backing or joint, usually averaging about 35 feet, in a horizontal direction. It was then sunk vertically from 7 feet to 9 feet, the headings originally being started about 5 feet above the floor of the quarry. Having been thus sunk vertically to about 3 feet below the floor of the quarry, it was spread out horizontally again, usually in two directions, parallel with the face of the quarry, and returned towards the face about 3 feet, forming the chamber in which the powder was placed. The tamping was then inserted, carefully rammed, and the mine exploded by galvanic battery.

Mr. A. GILES observed that, although valuable information had been given as to the cost and construction of this great work at Holyhead, the Paper did not seem to invite discussion as to different forms of breakwaters. That subject had been ably discussed in a Paper brought before the Institution by Mr. Scott [1] in 1858, and he was sorry not to see present many gentlemen who had had experience in the construction of breakwaters, and who could say whether the various forms proposed in that Paper had been successful when carried out. The President had referred to this question in his opening address on taking the chair,[2] and said it was a crying want of this country, that there were no national works of this sort on the east coast. Everybody must agree in that opinion, and he was quite certain that the Engineer who could point out to the Government a means of accomplishing those grand objects, at a cost and in a time much less than had been consumed at Holyhead, would do more to save the lives of seamen, and prevent shipwreck, than the greatest agitator of the present day would ever do. The Author was not responsible for the design of the breakwater at Holyhead, nor was Sir John Hawkshaw, nor

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xviii., p. 72.
[2] *Vide ante* p. 5.

Digitized by Google

the late Mr. Rendel, and any one looking at the outline would see that it had not been designed as it at present appeared, from the beginning. It had been altered, and in fact patched. If it had to be designed afresh, to afford the same accommodation as at present, it was quite evident that it would never be carried out in a concave line towards the sea. From long thought on this subject he had formed an opinion that a breakwater could be constructed at something about one-half the cost, and certainly in less than one-half the time consumed at Holyhead. The method adopted here was a legacy from olden times, from the great work at Plymouth. The means of carrying it out at Holyhead were the most favourable that could possibly be imagined. There was nothing to be done but to throw a mountain down into the sea close at hand. It was, however, a question among engineers whether an upright wall would not afford a better breakwater and require less repair than one with a long sea slope. He maintained that such a breakwater could be made, but not with stone, and he looked forward to the time when such structures would be made of iron, filled (it might be) with concrete, but at all events with an iron skin. He believed that such a breakwater with a skin of either cast or wrought iron, founded on 'pierre perdue,' could be made at about one-half the cost of a long slope. No one could be surprised that any Ministry should hesitate before undertaking the necessary works for harbours of refuge, as at present carried out. He thought there must be some error in speaking of fourteen and a quarter years as the time occupied at Holyhead, because he well remembered going over the works with Mr. Rendel some years before that gentleman's death, which happened in 1856, and the Paper alluded to the completion of the work in 1873. He must, however, say that to call this work simply a breakwater was a misnomer. It was a pier as well as a breakwater. If a breakwater only had to be constructed, it should be a mole of a round or pointed arch form, a certain height above high water, but so that the sea might break over it. Such a work could be carried out at much less cost than a pier. Taking the cost of the present work at £1,285,000, and charging 3½ per cent. on that amount, with £10,000 a year for maintenance and repair, it would require a toll of 1*s.* per ton on all the vessels now using the harbour to make it pay; and if such a toll were charged few vessels would enter the harbour. This class of national work, therefore, could only be undertaken by Government.

Captain CALVER did not know that he could add much to what had already been said, in evidence and otherwise, about Holy-

Digitized by Google

head. In fact, some persons thought too much had been said, but still it was always possible to add a few words more, and those few he would now supply. The detail of the construction of the breakwater was not a matter within his province, and he therefore should not meddle with it; the points most interesting to him were the physical and the nautical character of the harbour. To those two points his remarks would be confined, and he should be sorry if anything was said to cause the slightest offence to any one. Their object was the promotion of truth; they had to deal with measures, not men, and that must be kept strictly in view in the remarks he was about to make. It was generally admitted that the form of Holyhead harbour was a mistake. From the outset, the great error arose from assuming the necessity for putting a solid work over the Platters. If the subject had been wisely considered, it would have been seen immediately that no work whatever was necessary between Salt Island and the Platters. The distance of exposure which that was supposed to provide against was only 1½ mile, and therefore, in the heaviest gales, there could not be any fetch to require cover from; but that idea having been adopted, whoever was responsible for it, the solid work over the Platters entirely governed the projection of the north breakwater; and to make it of the usual harbour form after coming out from Soldier Point, it was doubled in sharply to the south-east, leaving, as originally intended, a distance of 850 feet only between the prongs of the Platters rocks and the toe of the breakwater. Nautical men would at once see that no large ship could get into a harbour so formed, because the time when refuge was required was during south-westerly gales, when the wind was directly out of the entrance. A vessel of 1,000 tons measured 250 feet, bowsprit included, and if a vesssel of that size were working into the harbour, as designed and carried out, she would have as a matter of safety to tack one length short of the breakwater on one hand, and one length short of the Platters on the other, leaving little more than her own length to work in, which would be an impossibility. Thus it would be seen there were two principal mistakes in the original projection of the harbour: first of all in assuming the necessity for a solid work over the Platters; and next in not seeing that a harbour with a narrow entrance of that sort was nautically defective, because it could only be partially used at the time when refuge was required. As previously remarked, if there had been no fettering—it might have been financial for all he knew—it was quite clear that the northern break-

Digitized by Google

water would have started from where it now began, curving in a generally easterly direction, and have terminated perhaps not far off from where the head was at present. Such a breakwater, while 900 feet shorter than the present one, would have included 68 acres of additional deep-water space, and have rendered the harbour, nautically speaking, infinitely superior to the existing one. The extraordinary thing was that these simple facts were not recognised at the time the harbour was designed. The harbour being completed, however, the only alternative was adopted, namely, the extension from the elbow opposite Salt Island to the present termination, which doubled the value of the harbour, as he stated in evidence in 1857, by enabling large vessels to enter the comparatively unencumbered outer roadstead, and to take up a berth in safety. It was possible that an explanation might be afforded for these matters, as in the case of an officer whom he had met many years ago, who was in the habit sometimes of making mistakes, and so sure as he made one he began to give a long explanation of how it occurred. The answer given him in a kindly way was—"Well, my friend, I do not want your explanation; the thing which concerns me is your mistake." So with regard to the projection of the Holyhead breakwater; there might be an explanation, but there was the mistake, left as a legacy not only to the engineering profession, but also to the whole country. Every candid member of the Institution must agree, that a system which admitted of such mistakes being made certainly offered ample room for improvement. He did not notice anything in the Paper about silting, but in the year 1857 when he was sent there to make an elaborate survey of the harbour, he found that something like 15 or 18 inches of silt had formed in it. It was suggested that it was merely the débris of the works, but one day finding the harbour full of turbid water, he went to the masthead, and noticed that the water was charged to a considerable distance seaward. The harbour was not a close one any more than that at Portland; still there ought to be a small amount of silt in it, and it would be interesting to hear from the Author if any test observations had been made with respect to it.

Mr. J. N. Douglass did not agree with Mr. Giles about the advantages of an iron and concrete structure in such a situation, and thought if the work at Holyhead had to be commenced anew the rubble mound would still be adhered to, considering that the mountain was so near at hand. Any one looking at the natural slopes of the rubble mound must be forcibly struck

Digitized by Google

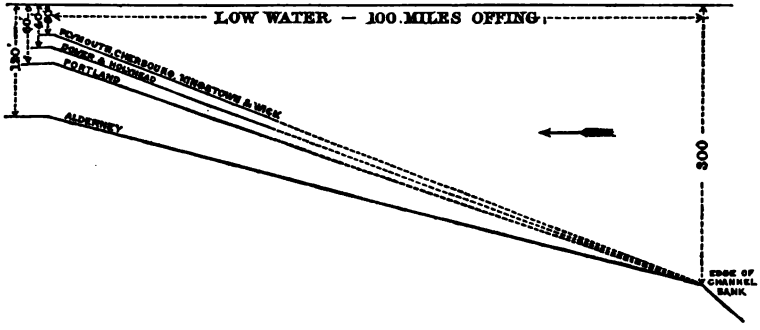
with the conviction, that the breakwater might have been constructed with one-half the amount of material. From high water down to low water the slope was 1 in 12; from that level to 12 feet below low water the slope was 1 in 5; and from the latter level to the bottom the slope was 1 in 2. If the latter slope were brought forward on the section so as to cut off about half the material, and the rubble mound were terminated vertically at say 15 feet below low water, and the superstructure were carried up in solid work, the cost, in his opinion, would have been considerably less than that actually incurred. With the surface of the rubble mound as suggested, the materials would have had less tendency to travel laterally towards the end of the breakwater. He fancied that if Sir John Hawkshaw had to do the work again he would carry it out in a different manner. He quite agreed with Mr. Giles and Captain Calver as to the unfortunate form of the breakwater, but it was now too late to remedy it; the members of the Institution might, however, congratulate themselves on the fact, that the Engineer who designed the work could not be saddled with the entire responsibility of the defect. One point with regard to the form had not been referred to, namely, its weakness. It was unfortunate that the increased difficulties experienced in consequence of that weakness, due to the hollow form, had not been referred to in the Paper. It was evident that with storms from the south-west, the force of heavy seas would be concentrated in that hollow; and although extra precautions had been adopted, the extra force at work near the middle of the hollow was quite apparent. As had been already pointed out, a shorter breakwater might have afforded perhaps double the present available area of sheltered water, and such a breakwater would have had the advantage, from its form, of greater strength to resist the heavy seas to which it was occasionally exposed. The square form of lighthouse had been referred to as being more commodious than a circular one, but he did not think that the square tower could be frequently adopted. At Holyhead there did not appear to be any objections to the square form, but it sometimes occurred at a lighthouse that it was required to cut an additional window to meet some new requirement of the coast navigation, and it would be awkward to do this at an angle of a square tower. He had the pleasure of assisting Sir John Hawkshaw in the illuminating arrangements of the lighthouse at Holyhead. It was the first instance in which one of the improved Trinity House oil burners was introduced permanently at a lighthouse for working at single or double powers. These

Digitized by Google

burners were so arranged that during clear weather, when a powerful light was not required, they could be worked at single power by suppressing some of the inner wicks, and whenever the atmosphere was hazy, and a more powerful light was required, the suppressed wicks could be brought promptly into action without extinguishing the light. A saving of half the full consumption of oil was thus effected during clear weather.

Mr. REDMAN wished, before the discussion closed, to refer to a diagram (Fig. 11) he had prepared showing the comparative

FIG. 11.



conditions of the various national harbours. A mere inspection would show how great a difference there was. The opinions advanced in that room, in Parliament, and elsewhere, with respect to the great question of national harbours, were not more diverse than were the conditions which surrounded the sites of the harbours, although they were often spoken of as if they were identical in circumstances: the 30 feet depth at low water applying to Plymouth, Cherbourg, Kingstown, and Wick; the 40 feet applying to Dover and Holyhead; the 60 feet to Portland; and the very great depth of 120 feet to Alderney. It was generally found around the coast that there was a defined edge of deep water, the edge of the channel bank, which gave a tolerably uniform offing of 100 miles of comparatively shallow water, and the waves generated therein would be increased, as there was an uninterrupted expanse of deeper water beyond. But if the offings of Alderney, Plymouth, Wick, Kingstown, Dover, Portland, Cherbourg, and Holyhead were compared it would be seen that the conditions were exceedingly variable. At Alderney the depth was from two to four times that at other harbours, with a body of water represented by a section from low water to the lower line; whereas the other

Digitized by Google

harbours were affected by a body of water represented by the other lines. With the exception of Alderney, Plymouth, and Wick, which were all three open to the ocean, the offings of the other five harbours would be terminated by the opposite coasts, and the distance thence to the edge of the channel bank would be a varying quantity. If the cross sections of Plymouth, Cherbourg, Portland, and Delaware breakwaters were compared with Holyhead, it would be seen that the slopes were almost identical, those slopes being made by the ocean waves, the average base being 300 to 400 feet in width; and taking that into account the cost at Holyhead was not excessive compared with other similar works; the average cost of such works ranging from about £300 per foot at Dover to about £100 for Portland. There was no doubt a great deal in what fell from Mr. Douglass, whose observations, as he gathered them, were to the effect that the enormous sectional area of breakwater might have been greatly reduced by putting in a deep-water vertical wall instead of leaving Nature to do the work. By those means the sectional area of the rubble mound would be reduced 40 or 50 per cent. The question of the outline of the pier on plan was one that was left by previous generations; and there was no doubt that had a curved line been projected convex seaward from the commencement of the pier to the head it would have given over 60 acres additional, or 10 per cent. of the area inclosed. That was an *ex post facto* criticism easily made, which was transparent on the plan, but it still appeared strange that the breakwater should have assumed its present form. It arose, however, from the fact of the increase in the size of shipping, and the consequent inclosing of a larger area than was at first anticipated.

Mr. ABERNETHY, Vice-President, said the Author had lucidly described the *modus operandi* adopted in carrying out the work, and also the nature of the construction, but he should be glad to know whether Mr. Hayter considered the form of construction adopted at Holyhead the best adapted for the formation of deep-water breakwaters. In 1860 the subject was discussed at the Institution, and he then objected to that form for various reasons, among others that the long slope seaward, of the rubble mound, would convert the wave of oscillation into a wave of translation, and that the continued action of the sea on the mound would eventually, by attrition, wear it into a mass of boulder stones, and reduce them gradually until they became a shingle beach, so that the cost of maintenance of a work of that class would be very great. He had received certain information, whether accu-

Digitized by Google

rate or not he could not say, that the result at Holyhead had been, that the action of the sea on the rubble mound had not only reduced it to boulder stones, but even to small shingle almost approaching gravel, and that, in order to preserve the work, it would be necessary continually to renew the rubble mound. He wished to elicit from the Author whether this was the fact or not. He had also been told that, as a result of the rubble mound being so reduced, the action of the sea at the hollow bend had created a great chasm, and that a considerable portion of the material which had been so removed had been carried round the head of the breakwater, forming a shoal within the harbour. From the experience of recent years, he was convinced that the proper form of construction for deep-water breakwaters was as nearly as possible the vertical wall. On a small scale, works of that class had been already carried out successfully in the harbour of Aberdeen. The foundation then was composed of bags of concrete of 50 tons each, dropped from barges, forming a continuous base for a solid superstructure. The work had been exceedingly effective up to the present time; it resisted the action of the heaviest seas, and promised to be maintained at a small cost for a long period of years.

Sir JOHN HAWKSHAW, Past-President, referring to Mr. Abernethy's suggestion, said that if a vertical wall had been built at Holyhead from the bottom of the sea, and made strong enough and good enough, it would have been a better structure, but would have cost about double the present one. He thought the fact had been overlooked that this breakwater, reckoned to high water, was at the outer end 75 feet deep, and the average depth was about 58 feet. To build a vertical wall in so great a depth of water in that situation, although it would no doubt be a good thing, would certainly cost so large a sum that he did not think any Government could undertake it. At Alderney a mound had been made, and then a wall placed upon it; but the plan had not proved successful. There was a rule amongst old engineers, which he thought a fallacious one, that provided the foundation of the vertical wall was taken to a certain depth, say 15 feet, no wave would act below that. He had no hesitation in saying that there was no such limitation to the action of waves. That action must depend upon the extent of the sea, which would vary according to the situation, and it was, according to his experience, quite untrue to say that if a wall was built 15 feet below water it was perfectly safe. The depth must be greater, and that would increase the expenditure. A good illustration of this was afforded by the pier at

Digitized by Google

Dover, than which he knew none of better structure and quality, but it had cost nearly twice as much per lineal foot as the breakwater at Holyhead. It was a vertical wall, and was suitable there, because it was required to bring steamers up to both sides of it; but if the same plan had been adopted at Holyhead, the expenditure would have been nearly double what it had been. With regard to some of the questions which had been put, he was not aware of the consequences which Mr. Abernethy had spoken of. No doubt some of the small stuff on the top of the mound rolled backwards and forwards, and assumed the form of pebbles; and there would be a slight wear of the foreshore, the extent of which would not be ascertained until the mound had been washed down to its normal form. So far, however, there had been nothing at all beyond what he had expected or anticipated. He might say this because the original design was not his, but belonged to his lamented friend, Mr. Rendel, by whom this particular mode of dealing with the Holyhead breakwater was devised. At the same time, he did not hesitate to defend it. It was scarcely worth discussing the objections to the bend. Nobody would now advise a breakwater of that shape; but it arose from the fact that the original conception was for a small harbour, and although Captain Calver had spoken as though in those days such things were not properly considered, nevertheless it had been considered almost *ad nauseam*. The opinions of several Engineers and nautical men had been taken. Many of them said it was too large; some thought it a monstrous proposition to make a harbour there at all; and it was at all events as large as the Government of that day could be induced to undertake. It was afterwards thought to be too small, and there was then nothing for it but to take a departure in another direction, which led to the bend. Such a work would now take a straight line, or a slight curve outwards; but the present form was rather a matter of history, and it was no use now discussing it. Mr. Giles had said that by using iron and concrete he could build a breakwater in one-half the time and at one-half the cost. Nothing would give him greater pleasure than to receive some suggestions as to how, in such a situation, this could be done; but he was quite sure that a breakwater of such materials, in such a situation, would cost double the sum that had been expended. If Mr. Giles could show that, in so great a depth of water, he could make a breakwater the same length at half the cost, he ought certainly to have the building of breakwaters everywhere. With regard to the question of the square lighthouse, it would be wrong to put one in a situation like the Wolf Rock, or the Edystone,

Digitized by Google

where the waves would beat upon it, but at Holyhead the light-house was far above the waves.

Mr. GILES said Sir John Hawkshaw must have misunderstood his remarks. He had never proposed iron and concrete for that situation; his thoughts were more particularly directed to the Yarmouth Roads, and the East Coast breakwaters.

Mr. HAYTER, in reply, said that Sir John Hawkshaw had answered many of the questions. It was not the case, as Captain Calver had supposed, that there had been any material silting. There had been a little deposit at the toe of the rubble mound on the harbour side, arising from material washed out of the mound; and there had also been some deposit where the ships mostly congregated in the harbour from cinders and refuse thrown over by the sailors. There was not likely to be any important silting, properly so called, inasmuch as the coast was rock-bound, the sea was clear, and there was no river or large stream running into the harbour.

Allusion had been made by Mr. Douglass to the weakness, as he alleged, of the breakwater at the second or outer bend, consequent on its form; and he stated that it had given way at that point. This was not so: the work had never given way there, and was never likely to do so, the foreshore being made at that point extra long, and so amply full that a large quantity of loose stone was now piled up against the superstructure which had not been washed down by the sea. Mr. Douglass also alluded to the saving of cost that would be effected if the foreshore were finished about 12 feet below low water, and the superstructure carried up from that level. It was true that this form of construction, to which he had given consideration, would save expenditure, especially at a place where the rise of the tide was so great as at Holyhead, but such a rubble mound would not get consolidated like the mound at Holyhead. Hence a superstructure on a rubble mound not carried up would be on a bad foundation, and would settle and crack; and if it could be maintained at all, it would entail a large yearly expenditure, as had been experienced at Alderney, while the superstructure at Holyhead had remained sound. No doubt, *cæteris paribus*, a vertical wall was a better form for a breakwater than a long slope, as in the latter case a new force was introduced by the conversion of a wave of oscillation into a wave of translation, and so far he concurred with Mr. Abernethy; but such a breakwater could not have been built at Holyhead except at a prohibitive cost. There was no reason to believe that if the work had to be done over again, the mode of con-

Digitized by Google

struction initiated by the late Mr. Rendel, and followed by Sir John Hawkshaw, would be departed from in any material degree. There was no foundation for the statement that the action of the sea at Holyhead on the rubble mound had reduced it in strength; the rubble mound, now that it had assumed its normal slopes, was stationary, or nearly so, and did not materially deteriorate. Mr. Giles had assumed a sum of £10,000 for maintenance. Hitherto scarcely anything had been spent on this head, and it was not likely that maintenance would ever cost a large sum, as the work had been substantially done.

In heavy gales the staging for a few bays near the end of the work in progress, where it was not sufficiently surrounded with stone or protected, was generally thrown down, but although damaged it was not all lost. It found its way to the opposite coasts, and most of it was brought back and re-erected. As the staging advanced, considerable portions landward could be taken up and used over again. Taking everything into consideration, the staging might cost in the aggregate about £150,000, or about 5*d.* a ton of stone deposited.

A good deal had been said about the form of the breakwater, and he had stated in the Paper how that form had originated. There could be no doubt that if, at the commencement of the works, the point where the breakwater would ultimately terminate had been known, it would have been made either straight throughout, or with one bend only. The form, however, of the breakwater was not altogether a misfortune. It might be unsightly, when viewed from certain positions, but the oblique direction of the end length rendered it easier for vessels to enter the harbour, and sheltered a larger area of deep water, than if it had been continued in a straight line with the central portion.

Mr. W. D. Cay stated, through the Secretary, that he had visited the Holyhead Breakwater works in 1867, and had been much struck with the excellence of the arrangements for carrying out the work. In reference to the structural design of the breakwater, he believed that, after the lapse of about half a century, the cost of maintenance would be considerable, owing to the wearing of the stones of the rubble mound, forming the foreshore, by the action of the waves; the tendency being to reduce the rubble to shingle, which would be washed down to a flatter slope than at present, and which would be moved about by storms in a manner dangerous to the stability of the foundations of the masonry superstructure. It would then require a considerable amount of rubble to be added

Digitized by Google

to it annually, or it might be protected in a permanent manner by concrete work. He believed that, supposing materials for concrete to be obtainable in the neighbourhood, a concrete breakwater could now be constructed at about 18 per cent. less cost than the existing one, while the expenditure for maintenance would be comparatively trifling.

Sir JOHN COODE observed, through the Secretary, that it was all very well to be wise after the fact, but it was only fair to state that among the many arguments adduced against the design of the late Mr. Rendel for Holyhead Harbour, when it was first proposed, it did not appear that there was at that time any allegation whatever as to its being too small, but on the contrary, for in some quarters it had been argued that no harbour at all was necessary there; experience had, however, completely proved the fallacy of that view.

With regard to the wagons referred to in the Paper as having been designed by the late Mr. G. C. Dobson, he was able to say that the determination of the best kind of wagon for the particular purpose had been a matter of much consideration at the time, and having used more than two hundred of them elsewhere, he could state that the then somewhat novel arrangement, designed by Mr. Dobson, had proved most successful for the special purpose for which it was devised.

Mr. J. A. MCCONNOCHIE stated, through the Secretary, that it appeared to him, when recently examining the work, that the settlement in the superstructure had been unusually little. The assertion that if the foundations had been carried lower the mound might have been much reduced, with considerable saving in cost, would hardly bear reasoning out. Breakwaters might be divided into two classes, viz., those with high superstructures, of which that at Holyhead was a type, and those in which the works were not carried higher than about the level of high water spring tides. The effect of the sea on the two classes of works was very different. In the case of high superstructures, unless they were protected by a high foreshore, which was the distinctive feature at Holyhead, the rebound of the sea was of the most destructive character; it immediately found out any weak places which resulted from settlement in works built on a rubble mound after every possible care had been taken, and a breach speedily ensued. The trifling saving in cost resulting from carrying down the foundations, lowering the foreshores, and reducing the mound, would, after setting the costly diving work against the cost of rubble mound, be entirely disproportionate to the increased risk involved by the

Digitized by Google

alteration; a greater height and weight of superstructure would require to be built on the mound, necessarily causing increased settlement with its attendant dangers, and with a lowered foreshore it would be extremely difficult for an engineer to determine at what level short of the natural bottom it would be safe to commence the superstructure. The lowered foreshore would also require heavier stones, be more costly to construct, and be more difficult to maintain. It was highly probable that, except in special cases, high superstructures would be abandoned in the breakwaters of the future, as that feature had a material bearing on the cost of the work and on every detail of the design; but, given an abundant supply of stone at hand, and that a high superstructure was required of the character of the masonry here adopted, he was of opinion that the result of experience in such works, from the date of the commencement at Holyhead to the present time, showed that for safety and efficiency, the section designed by the late Mr. Rendel could not be much, if at all, improved.

Allusion had frequently been made to 'waves of oscillation' and 'waves of translation,' but so far as ordinary breakwater works were concerned it was a distinction without a difference, and for all practical purposes the waves were waves of translation.

Breakwaters of iron filled with concrete had been suggested as the economical type for the future, but the economy of this construction was at least doubtful, and recent examples showed that concrete without iron served every purpose.

Mr. W. Parkes remarked, through the Secretary, that the original design and early stages of the work, dating from a quarter of a century ago, were rather subjects of professional history than matter for contemporaneous criticism. The work itself must be looked upon as affording data for general conclusions, and not as an example to be followed in future practice. Yet even viewed by the light of modern practice, which in this branch of engineering had rapidly advanced since the Holyhead breakwater had been commenced, it must be pronounced a successful and fairly economical work. It had the great advantage of an abundant supply of suitable stone, which could be thrown into the sea so as to form a huge mound at a cheap rate; and the skill of the Engineer had been shown rather in producing so many tons of stone at the least possible cost, than in disposing of that stone in the most advantageous and economical manner. Examples were to be found elsewhere of attempts to apply the latter principle, but on the whole, the results perhaps had not been so satisfactory as at Holy-

Digitized by Google

head. If, however, stone had not been so plentiful and cheap, the Engineer would have been driven to adopt some other system, and to economise in the number of tons as well as in the price per ton. Hence, though other works might be more open to criticism than the Holyhead breakwater, they had yet done more to advance this branch of engineering. A Holyhead mountain, or a Portland island could not always be secured as the starting-point of a breakwater; and engineers working at a less advantage in this respect had been led by necessity to adopt other systems, in which economy in quantity of material had more than compensated for the extra cost of stone. It might not be without interest to inquire what the result would have been if one of these systems had been adopted at Holyhead. The total cost per lineal foot had been given as £163, but this included large items such as plant and preliminary expenses, and the head, which could not fairly be brought into comparison on the two systems. A better result would be obtained by taking a given section, say in the average depth of 40 feet, and calculating the cost of this upon the rates given in the Paper. He found that 1 lineal foot of the rubble base in this section contained 786 tons, which at 2*s.* 5*d.* per ton gave £95. Add to this £36 for the superstructure, and £131 would be the cost of 1 average foot without the large general items before spoken of. Now suppose that, instead of the wide foreshore of about 180 feet to seaward, and reaching to high-water level, the sea-wall had been built up vertical from a depth of 20 feet at low water, and the foreshore extended at that depth 50 feet seaward; that the wall were carried up 30 feet wide with concrete blocks of about 30 tons weight to a height of 10 feet above high water, and the remainder of the section made the same as the existing work; also allowing that, in consideration of the smaller quantity of rubble stone, the rate be taken at 3*s.* instead of 2*s.* 5*d.*; on these data he calculated that the cost would have been £111 per lineal foot instead of £131—or a total saving of about £160,000.

He would not go into the question of whether, with this fundamental difference, on the sea side, the remainder of the section would be the most suitable; probably it would not, but the above calculation seemed to give an approximate measure of what might have been saved if the experience of the last twenty-five years could have been anticipated when this work was designed. On the whole, he did not think the result of the comparison was unfavourable to the judgment of the designer; though, with the experience of the present day, a different section would probably have been adopted.

Digitized by Google

Mr. STONEY observed, through the Secretary, that the Paper, though replete with facts of the most valuable kind, contained no expression of opinion, either favourable or otherwise, regarding the section, mode of construction, or future repairs of the breakwater. Now, considering the large practical acquaintance of the Author with various branches of civil engineering, it was legitimate to expect an opinion which would be of value in guiding future practice. Among other things, he would gladly know whether the Author approved of the cross section of the breakwater; what his views were respecting its durability, and how it was proposed to deal with the repairs which could not be regarded as other than imminent; for the rubble foreshore, on the permanence of which the stability of the superstructure mainly depended, was rapidly turning into gravel under the disturbing influence of the waves: in some places it had been washed away from the lower part of the superstructure, and in others piled up to within a few feet of the parapet, so as to form gigantic waves, the height of which from hollow to crest approximated to that of the masonry superstructure itself; and, if report spoke truly, this foreshore was already travelling round the pierhead with a rapidity somewhat surprising, seeing that only two and a half years had elapsed since the completion of the work in 1873. The cost of the staging in a depth of 50 feet at low water was stated to be nearly £20 per foot. It would be interesting to know the cost of the staging for the whole work, for it was generally believed that storms occasionally destroyed many thousand pounds' worth of staging in the course of a few hours: as, for example, in the gale during which the "Great Eastern" was so nearly wrecked inside the harbour on the 26th of October, 1859. Perhaps, also, the Author could give the separate cost of the other items of plant—such as steam gantries, wagons and locomotives, &c.—as this information was valuable in what might be called the comparative anatomy of different modes of construction.

Digitized by Google

February 8, 1876.

GEORGE ROBERT STEPHENSON, President,
in the Chair.

No. 1,435.—"Carlingford Lough and Greenore." By JAMES BARTON, M. Inst. C.E.

THE Author proposes in this Paper to give an account of some improvements effected in the Lough of Carlingford on the east coast of Ireland, during the past few years. This Lough, shown upon the accompanying map (Plate 4), lies about halfway between Dublin Bay and Belfast Lough. It is sheltered by a natural rock barrier extending from Haulbowline Lighthouse to Ballagan Point, on the south side of the entrance. This barrier is uncovered almost throughout at low water of spring tides, and part of it is above high water. The entrance to the Lough is confined to a deep-water channel between the Haulbowline Lighthouse and the Scars which extend from the Soldiers Point. The natural entrance, 3 fathoms deep, is about 700 feet wide. Outside this, however, there is a bar—a tail of Cranfield Point—of blue clay and boulders, which extends across the entrance from the north side in a south-west direction, and upon which there was formerly a depth of 7½ feet of water at low tide. South-west of this shoal there exists a channel more than 18 feet deep throughout; it was discovered by the late Commander Hoskyn, Superintendent of Charts at the Admiralty, who surveyed the Lough, and laid down the channel in 1857 for the first time, and it is called the Hoskyn Channel. Commander Hoskyn gave evidence, as to the great natural capabilities of Carlingford Lough as a harbour, both before the Royal Commissions and the Parliamentary Committees who have since dealt with questions relating to it. This deep-water channel, he stated, might, if properly buoyed and lighted, suit steamers; but having two turns at right angles, it could not suit other vessels, and further experience has shown that it would be dangerous even for steamers in rough weather. Within the Lough there is a large area of deep water, safe for anchorage in all weathers, and with good holding ground; the extent for anchorage over 18 feet deep at low water of spring tides is about 1,200 acres.

For above one hundred years the navigation from Carlingford

Digitized by Google

Lough up to the town of Newry has been the subject of much engineering thought. Reports were made by Mr. Nimmo and Sir John Rennie, and a ship canal and lock were constructed under the latter; but the bar was not then considered with a view to its removal.

In the year 1845 the Commission upon Tidal Harbours took evidence upon the subject of cutting a channel through the bar from Mr. John Ramsay, who had made some borings and examined it. The Commissioners reported that: "To render this Bay available as a harbour of refuge, the bar should be deepened to at least 18 feet at low water spring tides, and this for a breadth of two cables' length, or 400 yards; the loose boulder-stones should all be picked up, the limestone skirts of Haulbowline Island should be removed, and the Earl and other rocks blasted away. The estimate for deepening the bar was £50,000, but even if double that sum were required, it would be well bestowed in accomplishing that which could not fail to prove an invaluable boon to the numerous vessels navigating the Irish Sea, and, as such, is justly entitled to be considered an object of national importance."[1]

In the year 1859 the Commissioners on Harbours of Refuge recommended the improvement of twelve harbours, of which two were in Ireland, Carlingford and Waterford; and of Carlingford they reported: "Lough Carlingford, on the east coast, offers a spacious natural harbour in the very position that a Life harbour in this district would be desirable, namely, in the track of Liverpool vessels bound through the North Channel, and of ships from the Clyde bound south through the Irish sea."[2]

The Government brought in and passed, in the following years, the Piers and Harbours Act of 1861 and 1862, by which harbour works were facilitated and loans provided, by the Harbours and Passing-tolls Act, 1861. Under these Acts one of the first applications was made, by the advice of the Author, in the autumn of 1862 to the Board of Trade by the directors of the Newry Navigation Company. They asked for powers to cut the bar of Carlingford, and to form a channel through it 600 feet wide and 21 feet deep at low water, at a cost, including the removal of some rocks, of £100,000; and it was proposed to levy rates upon all vessels entering the Lough to pay the interest and instalments of a loan for the

---

[1] *Vide* Tidal Harbours Commission. Second Report of the Commissioners. Appendix, p. 63*a*. London, 1846.

[2] *Vide* Report of the Commissioners on Harbours of Refuge, vol. i., p. xi. London, 1859.

Digitized by Google

purpose. Severe opposition arose, and the project was abandoned for that year.

In the year 1863, however, some gentlemen interested in the Irish North-Western railway, in concert with other local interests, took up the project, and applied for a provisional order for cutting the bar. This was passed in 1864; and in 1866 a loan of £80,000 was made by the Public Works Loan Commission upon the security of the rates, after an investigation and report upon the project by Sir John Coode, M. Inst. C.E.

The exposed position in which this work had to be done, and the difficult material of which the bar is composed, rendered the cost of the operation somewhat exceptional; and though the prices were very different from that for ordinary dredging, they were probably as low as the work could be carried out for, and lower considerably than the only tender obtained from contractors. The sea upon the bar of Carlingford was too rough for dredging when there was any wind from the southern half of the compass, and if it blew heavily from the southward the water was too rough for two or three days afterwards; hence the time for work was very limited, and a special dredger had to be designed. The dredger was so constructed that it could lie safely at anchor on the bar in a sea in which dredging could not be continued, and thus be ready waiting for opportunities of working; it was self-propelling, having a pair of twin screws. The days in each year during which dredging could proceed varied from sixty-seven in 1871 to one hundred and thirty-one days in 1873, and upon many of these days the work was limited to one or two hours. The tonnage raised in one season varied from 50,060 to 99,720.

Arrangements were made to work every quiet hour in summer, and in calm weather the same set of men were employed, sometimes for two or three weeks, from sixteen to nineteen hours a day. The best result was obtained by giving each man a bonus in money, according to his position, for every 1,000 tons of material raised in the fortnight, in addition to his standing wages. The material consisted for the most part of plastic blue clay, occasionally free of all stone and fine enough for pottery work, but generally with boulders of limestone, greenstone, or granite imbedded, and these varying from shingle up to stones of 4 tons weight.

The dredger was designed to excavate in a depth of 37 feet of water; and practically, operations were often carried on at a depth of 34 feet to 35 feet; the depth of channel excavated being 18 feet at low water, and the rise at high water of spring tides being 16 feet and 17 feet. The dredger was constructed by Messrs. Simons

Digitized by Google

and Co. of Renfrew, and was of such a model as to steam itself between the Clyde and Carlingford without a tug. The engines are of 60 nominal HP. The mode of proceeding was by arc-dredging; the dredger, being held by six anchors and two backing anchors, was moved in her work by six steam winches, capable of reversing instantly, and working through grooved friction-wheels. The buckets are large, and have strong steel lips with projections to give an entrance into the hard material. The bucket girders are of wrought iron, 90 feet long by 4½ feet deep; the sides are plated with lattice bracing at the top and the bottom; the hoisting gear is frictional, and the tumbler bars are of steel. With careful handling the dredger will take out any stones imbedded in the clay, and lift in the buckets all stones of 30 cwt. and under; those over that weight, when cut out by the buckets, were thrown off by the arms carrying the lower tumbler, and were, as occasion offered, chained by a diver and raised on the deck by a crane constructed on the vessel's bow for that purpose.

The average amount raised per day when any work was done by the dredger was about 850 tons; but in the ordinary blue clay and stones of the bar about 150 tons per hour was the usual quantity, and 1,200 to 1,500 tons per day. On the north side of the bar a bed of gravel lay for some distance in the hollows in the clay; in this the dredger has on different occasions taken up over 3,000 tons in a day, and on one occasion over 4,000 tons in a day of about sixteen working hours. At the bottom of the excavation of the 18-feet channel, at one place (fortunately within narrow limits), a stratum of gravelly clay was met with so indurated that it was most difficult to cut by the dredger. The divers who first examined this stratum reported it to be rock *in situ*, but it was not so; of this material, however, sometimes not over 30 tons an hour were raised, and it was broken up almost into gravel before removal. The Author has also used this dredger in removing rock under low water in the Lough, first blasting on the surface with dynamite and then dredging away the material; and with care this can be done without risk to the machinery. The dredger was attended by a tug, one steam hopper-barge of 180 tons, and two hoppers without steam, of 150 tons and 120 tons. The material was deposited in deep water both inside and outside the Lough.

The channel is about ¾ mile long; the width is not yet fully completed; it is however cut to 18 feet deep at low water for a width of 300 feet, and to 14 feet for a width of 400 feet (Plate 4). The channel intended originally was 21 feet deep and 600 feet

Digitized by Google

wide, but it seems hardly probable that it will at present be carried further than 600 feet wide and 18 feet deep.

The total cost of the excavations, including the insurance of the dredging plant, which was a heavy item, parliamentary expenses, management, &c., has been approximately 1*s.* 9*d.* per ton; the actual work, however, for any one season varied from 1*s.* 4*d.* to 1*s.* 6*d.* per ton, including all expenses, and was equal to from 2*s.* to 2*s.* 3*d.* per cubic yard. An attempt was made at first to let this work by contract, but the only contractor who offered tendered at 3*s.* and 2*s.* 9*d.* for the 14-feet channel per cubic yard. It has therefore been carried out by the Commissioners of Carlingford Lough, under the Author's direction. A premium was given to the dredging captain and engine-drivers yearly for every ton of coals, by which the total annual consumption connected with the works was kept within 1 ton of coals to 100 tons of material raised, carried to deep water, and deposited; the actual tonnage was from 120 to 130 tons per ton of coals, of which about six-tenths were for dredging and four-tenths for carrying.

A series of Stoney's keel buoys have been laid down to mark the channel and the deep water of the Lough. Two leading light-houses, with small dioptric apparatus, have also been erected upon wrought-iron screw piles within the Lough, to indicate the line of the bar channel; they stand respectively 56 feet and 39 feet over low water. They were erected by the Author under the Irish Lights Board, and were paid for out of the Mercantile Marine Fund. The piles, 5 inches in diameter, are screwed with 18-inch screws into blue clay and gravel, and the structures, though very light, have withstood the heaviest gales.

In 1862 the Author submitted to the Directors of the London and North-Western and the Irish North-Western railways, then making traffic arrangements in the North of Ireland, that Greenore, in this Lough, afforded facilities for the construction of a deep-water marine station for railway traffic much beyond any other upon the Irish coast between Dublin and Belfast. Greenore lies about 3 miles inside the bar, the water is deep close to the shore, and a projecting point affords a natural shelter from the sea entrance of the Lough. These companies entered into arrangements to carry out the plan.

In 1845 a project for a railway from Newry to Greenore had been mooted, its terminus was to have been at a tidal-dock to be formed south of Greenore Point; this project did not reach a parliamentary committee, and, as its proposition was only for a

Digitized by Google

tidal service, it did not offer any special advantages, nor could it do so, inasmuch as the cutting of the bar was not part of the plan.

The project of 1862–63 was to bring the stream of traffic, gathered by different routes in the North of Ireland for England, to a point where a fixed hour steam service could carry it on at once, through a deep-water port, to Holyhead, which already existed as a deep-water station and harbour. The various tidal ports between Belfast and Dublin have steamers which carry a large quantity of live stock, general merchandise, and a considerable number of passengers, but the latter are chiefly third-class and to Liverpool. The London and North-Western and the Irish North-Western Railway Companies entered into an agreement to guarantee the capital for a company to construct a railway from Dundalk to Greenore, and a port at Greenore, with a branch railway from the Belfast line to the new line near Dundalk. Newry was left out, to some extent, by this proposal, and those interested in that town came forward under the advice of Mr. G. W. Hemans, M. Inst. C.E., with a project for a line from Newry, and the result was that both lines were sanctioned, the above-described branch being abandoned, and Greenore was to have been a joint work and joint station. The Newry project, however, was not sufficiently supported, and ultimately became the property of the Dundalk Company; the line to Newry is now being constructed; that to Dundalk with the port of Greenore have been completed.

The works at Greenore are not presented for consideration as either large or remarkable, but as an attempt to deal with the question, How best to provide, conveniently, for a combined passenger, goods, and cattle traffic, and as having a few points of novelty in detail.

Plates 4 and 5 prevent the necessity of a detailed description of the accommodation given. The object of the design was to provide for the convenient loading and unloading, rapidly, of steamers intended to come in and go out daily, the cargoes being passengers, general goods, and live stock, and if possible to make the passenger trade so distinct and out of sight and smell of goods (which often included fish), and of the cattle department, that a reasonably good class of passenger service could be secured. With this view the goods store is placed next to the face of the quay, as had been previously done at Holyhead by the London and North-Western Railway Company, so that cranes in the store can lift from the steamer's deck and load into the wagons direct, and *vice versâ*. There are two

Digitized by Google

berths for steamers, one with 14-feet depth at low water of spring tides, the other 17 feet deep, intended to be used not only for steamers but also occasionally for discharging grain vessels; there is also a short berth for a screw collier service, and a movable crane to do the work. These cranes are hydraulic, and the wagons are moved about the goods department by running heads worked by hydraulic power. The goods store is 450 feet long by 50 feet wide. The passenger shed is of the same size as the goods store, from which it is separated by a wall. The station and an hotel at the eastern end of the shed are built in connection with the passenger shed, and the passengers pass to and from the steamers by covered ways, 15 feet wide, under the rails of the goods store. These ways are light and airy; they each open out upon a movable stairway shown in Plate 5. This stairway is also 15 feet wide, divided by a centre balustrade, and leads to a stage which is raised or lowered according to the state of the tide, and the height of the deck of the steamer. The stages are each 36 feet long by 7 feet wide and 7 feet high, and are covered in. At each end of the movable stage is a door, which leads to the bridge or upper deck of the steamer, one end of the stage being in front of, and the other abaft the paddle-box. The doorways are 5 feet wide, so that a landing can be used sufficiently wide for two persons to walk abreast, and it is only necessary to have a landing about 8 feet in length. The stage is raised and lowered by hydraulic rams placed overhead (Plate 5), working four chains by which the stage is suspended, and accident is prevented by four racks and palls; the power is applied by a small lever actuating a stop-cock upon a 1-inch pipe. The stage remains in one position whilst the passengers are using it.

The stairs are somewhat novel, each step remaining horizontal in whatever position the stage may be, so that when the stage is down the steps form a level platform, and when it is raised they become gradually a stairway, until at the full height the tread of the steps is 6 inches. This is effected by supporting the stairs upon three light wrought-iron beams, attached at the upper end to the movable stage, and travelling at the lower end upon wheels upon rails; each step rests upon trunnions working in the beams which carry the weight, and the horizontal position is maintained by the balusters. The balusters are secured to the step, and turn upon a bolt in the top rail; the top-rail ends being fastened to the pillars of the stage, the perpendicular position of the balusters, and so the horizontal position of the steps, is maintained. This stage shelters passengers in going to and from the station, and they are

Digitized by Google

not brought into contact with the goods or cattle. The cattle department lies beyond the passenger shed, and the usual modern appliances are provided, as pens for sheep and cattle, covered houses for pigs, and water laid on in troughs in each pen. The pens open at one side to the platforms where cattle are discharged from the wagons; each herd is thus kept separate for the drovers; they then pass by a passage under both passenger shed and goods store, and out through the face of the quay wall to the bow or stern of the lower deck of the steamer.

Movable cattle-landing stages, capable of being set to suit the state of the tide, are also provided, the rise of the tide being 16 feet at high springs; these landings are 40 feet long, similar to an ordinary cattle-landing, but supported upon light iron girders turning upon an axis at the land end, and raised or lowered at the sea end by rackwork and a handle; they do not project beyond the face of the quay. Inside these, and rolling upon wheels, light stages are provided which run out, telescope fashion, to the deck of the steamer. To effect these arrangements the coping of the quay wall was raised 10 feet over high water; the foundations for the sea end and deep berths are 21 feet 6 inches below low water, the upper part of the quay 18 feet 6 inches. The foundation rests generally on sand and gravel, but for a length of about 100 feet on rock; the excavation was made by a dredger to the correct depth, and the bottom was levelled by divers for each portion as the work proceeded. The Author intended at first to form the whole foundation up to low water of Portland cement concrete, put in soft within close piling, and began with a length of 30 feet in this way. The concrete was made of 1 of cement to 2 of sand and 4 of shingle, with a few large stones, and was mixed in Ridley's mixers, and filled into skips, having a capacity of 1 cubic yard, with opening bottoms. These ran on trucks under the gantries, and were lowered from the stage by a winch; when close to the bottom the doors were tripped, and the concrete allowed to pass out quietly. Each day's work seemed to set fairly, but the divers reported soft places, and the Author felt it necessary to make further examination than was possible upon the surface; some piles were therefore drawn from the face and the face examined, when it was found that here and there thin strata of gravel separated the concrete for a considerable distance. Hoping that this defect might be prevented by greater care, a short additional length of 10 feet was tried, in which the pile joints were covered with canvas, and great care was taken to deposit the concrete quietly; but the result,

Digitized by Google

though better, was not such that the Author felt it safe to proceed. There were still small veins of gravel at intervals which could not afterwards be made good, and which by a little carelessness on the part of the workmen might become a source of serious danger.

The quay wall was therefore faced with concrete blocks, set by divers, and backed as far as the piling had been driven by soft concrete. The blocks were header and stretcher so as to key them into the soft concrete, and by the form of mould the header blocks keyed both themselves and the stretchers. These blocks were 4 feet 8 inches by 4 feet by 3 feet, and 5 feet 7 inches by 3 feet 2 inches by 3 feet, and their weight was about 3½ tons.

When the above change was made no further sheet piling was driven, and the remainder of the wall, until it approached the sea end, was faced by these concrete blocks, and the backface was built of soft concrete in bags, the hearting of the wall being of concrete deposited from skips, as described, without bags. This was commenced in 1870, and was suggested by the fact mentioned to the Author by the late Mr. Barry Gibbons, Engineer of Kingstown Harbour, that he had used concrete in bags as a foundation course for levelling upon the rock for the Carlisle pier in that harbour. The Author exposed concrete in bags to the action of the tide, and found that it set into a solid mass, and had not any of the cement washed out. The back wall of this quay was accordingly, from September 1870, built of bags of concrete, each containing a cubic yard; the bags were made to fit the skips, which had doors at the bottom, the top being left open until filled, and then the canvas was quickly laid across and sewn up, the skip was lowered from a gantry placed in position by divers, and then tripped and raised, leaving the bag in place. If a bag broke, which was very seldom, the whole was removed by the divers. This back wall was carried up to about 2 feet over low water; the bags fitted into each other, and locked into the soft concrete inside, so as to make a very satisfactory wall. The last length of 200 feet of the quay wall below low water, including the return which faced the current, was formed of blocks of concrete weighing 100 tons each. The position of these blocks will be understood from the diagrams (Plate 5). They were formed in moulds constructed of 3-inch planks, just above low water, and their size was regulated by the fact that they were to be lifted by flotation before high water; each block was of the full thickness of the wall, and constituted a 10-feet length of the wall, and half the height from the foundation to low water. They were lifted by two barges prepared for the purpose, with a suitable stage

Digitized by Google

and lowering winches, with endless screw gearing, and were suspended by four tie bars, with spade ends, which passed down through holes left in the concrete. These ends entered through oblong holes, in two cast-iron girders, underneath the blocks, and by turning a quarter round held securely. Horizontal shafts were left for the cast-iron beams to be put in at low water, and they were drawn out of the blocks after they were set.

The barges came over the blocks an hour or two before high water, the lifting bars were then secured to the cross-head, and the chains were strained by the winches until the blocks were nearly lifted (Plate 6); the tide in a few minutes accomplished the rest, and the barges carried away the block to the site, which had been levelled by divers; the block was lowered by eight men, who could always easily hold on and stop, and in one or two cases raised, a block. The setting was done by signals from the divers, and by leading marks. The setting of the first block was marked by a fatal accident. One of the tie bars, 2¼ inches in diameter, snapped across, and the pulley sheave thus freed sprang up, and killed one of the principal contractors, whilst the chain struck the Resident Engineer, and fatally injured him. This event delayed the work, and involved such a change of lifting arrangements as would seem to preclude the possibility of an accident, and finally the blocks were with the altered winch apparatus all safely lifted, carried, and set without further failure.

The open dock for the steamers to lie in, for loading and unloading, was formed by dredging. It was designed to be protected on the north side by a breakwater, which would also form a coal and fish quay. This portion of the project has not yet been carried out, and the need of such a protection, to prevent the steamers chafing against the quay-fenders, has only been felt on three or four days in the year. The current of the tide always sets out along the wall, so that there is no tendency to silt up. A thickness of about 18 inches of rock was excavated in a portion of this dock by divers. Above low water the wall was built of heavy rubble limestone masonry in lias lime mortar, the face work being set in Roman cement for 6 inches in. The coping is of limestone 16 inches thick; projecting stones of dressed limestone were left to form recesses to hold fender-piles, which were set every 12 feet, and to the faces of which rubbing pieces of rock-elm were secured by trenails. The fenders were fastened by bolts 6 feet long, built into the wall. The foundation of the wall was throughout protected in front by a filling, first of blue clay, to prevent the escape of sand, and then of stones. (Plate 5.)

Digitized by Google

One of the most difficult points of design was to fender off the steamers properly in front of the movable stages. The amount of direct strain to which a fender-beam unsupported for 20 feet is exposed, when a steamer comes against it broadside, or strikes it obliquely with her sponsons, is not easy to define, and the only data appeared to be, the strength of piling unsupported, for certain short lengths, which had failed, and others which had not failed under similar exposure. From such data the strains were calculated; and wrought-iron box fender-beams (Plate 5) of heavy plating were designed and carried down to low water. These beams were secured in recesses in the wall below, and were diagonally braced by box beams, and at the top brought by stays to bear against a box girder in the wall of the goods store, this girder being bolted down through the wall and strongly stayed behind, diagonally, to the foundation. The result so far has been satisfactory; and although occasionally these beams have been heavily pressed, there has not been a failure anywhere. Timber cushions take off the ordinary chafing, and give a safe place for a captain to run his vessel against, if from any cause he is forced to come alongside with unusual violence.

These works were commenced in 1869 and were completed early in 1873. Their total cost at and near Greenore, including gas-works, water supply from a distance of 2 miles, eighteen workmen's houses, hotel, hydraulic apparatus, &c., was about £130,000. The cost of the quay wall, which is on the average 45 feet high, including the foundations, except dredging the site, with extra payments to the contractor, and all staging and including fenders, except those connected with landing-stages, was very nearly £23,000; and its total length being 840 feet, the cost per lineal foot was £27 8*s*.

The Author is disposed to think that blocks of 100 tons or thereabouts, thus lifted, may be suitable for many works which could not afford the plant for very large masses. The cost of these (30*s*. per yard) was necessarily large, both as being the subject of after arrangements with the contractor and the quantity being small; this included everything but the first cost of barges and winches. The concrete was, however, rather expensive, the Portland cement being in the proportion of 1 in 6. The Author believes that, including all expenses, such work could be done, according to the locality and in quiet water, for 22*s*. to 25*s*. per cubic yard if the quantity was considerable. The contract price for the concrete in bags, when set, 23*s*., was above an ordinary contract price, for the same reasons that governed the price of the large blocks; if

Digitized by Google

opened to competition it would have probably been 21*s*. The liquid concrete placed below low water by skips lowered from staging was contracted for at 18*s*. per cubic yard, when set.

The London and North-Western Railway Company found almost the whole capital for the works at Greenore; and during the latter part of the construction from 1871, Mr. W. Baker, M. Inst. C.E. (their Engineer), was associated with the Author in the charge of the railway works. The Contractors were Messrs. Connor and Olley, whose managing Engineer and foreman was Mr. E. Manisty, Assoc. Inst. C.E. The Resident Engineers in charge of the harbour and bar works were, first, Mr. Robert Hickson, Assoc. Inst. C.E., and subsequently, Mr. J. G. Barton, Stud. Inst. C.E.; and the Resident Engineers at Greenore works were successively Mr. H. Foxall, Mr. Robert Hickson, Mr. Robert J. Hutton, Assoc. Inst. C.E., and Mr. Louis Trench, Assoc. Inst. C.E., to every one of whom a portion of the success of the works is due.

This communication is accompanied by a series of drawings, from which Plates 4, 5, and 6 have been compiled.

[Mr. W. A. Brooks

Digitized by Google

Mr. W. A. Brooks observed that the work was one to which unqualified praise could be given. The only possible objection he could raise was that enough money had not been spent. The works ought to have been considerably larger. They were of national importance, and should have been executed at the national expense.

Dr. Pole observed that if the bar was natural solid ground, no doubt the cut would be permanent; but if, on the other hand, it was one of those bars so frequently formed at the mouths of rivers by deposit, was it not to be feared that the same causes which had produced the bar would, if they remained in operation, tend to silt up the newly-formed channel? He merely asked for information, as he had no doubt the subject had been well considered in all its bearings.

Mr. John Grant asked the Author if there was much difference in the expense per cubic yard of the blocks in front and the bags of concrete behind, and whether he had reason to believe that, if the front had been made with bags of concrete, the work would have been less sound. It appeared to him that the foundation was as sound as it could be made by any method. No doubt it looked better to have square blocks in front, but under water that could be of no moment. He also wished to ask whether it was essential to have such large blocks as the 100-ton blocks which were used for 200 feet of the length. He thought that the remaining length of 600 feet when completed must have been quite as sound as the part made of the larger blocks. If they were not absolutely necessary, there would of course be a considerable saving in the plant required for raising and fixing such large bodies. This special plant was in the present case required for setting only forty blocks. The early failure in putting in the concrete was probably due to the fact that sufficient allowance had not been made for the cement that would naturally get washed away. It was intended to be 1 in 6; a strong mixture, no doubt, could it have been depended upon to remain amongst the gravel and sand; but in water that could not be assumed. A considerable allowance should always be made for the loss of cement put in in such a way.

Mr. Redman said the Author had not alluded to one point of interest—the tidal velocities, more especially upon the ebb, through the outlet. Carlingford Lough was between 9 and 10 miles in length, and 2 miles in breadth; it had an average rise at spring tides of 16 feet, and there was a vast body of water, which might be represented by about 200,000,000 tons, passing out upon

Digitized by Google

the ebb. A large quantity of that water no doubt escaped at the outfall, which was 2 miles in width from high water to half ebb; but a large proportion would pass out from half ebb to low water; and the velocity of the ebb-current through the low-water channels would be considerable. In the Admiralty Chart the highest velocity assigned to the surface of the Lough was 2½ knots an hour; and it was well known that the authorities were always wisely tenacious of giving information of that kind unless absolutely authentic. From the observations of Captain Beechey and others, the tidal currents in the Irish Channel in many places had been found to reach 4 knots an hour—notoriously so through the North Channel. In the Pentland Firth, and in the channels amongst the Orkneys, the velocities attained 7 or 8 knots an hour. The Admiralty Sailing Directions contained the caution not to attempt to enter Lough Carlingford except on the flood, or with a fair wind of sufficient force to overcome that of the ebb out of the Lough, showing how great the outset velocity was.

The oscillating gangway for foot-passengers was an ingenious adaptation of the parallel rule plan for the treads, and it was supplemented by a connecting movement between the upper bar of the railing and the balusters. Some years back he had drawn out the details of a landing of a similar kind for the lower reaches of the Thames, but it was only to be applied to the steps, and there was some hesitation in adopting it, lest the constant use of the gangways in the particular spot in question should render it dangerous to the foot-passengers, when incautiously using the staircase towards the top of a spring tide, when the treads would disappear, and accidents might occur. No doubt the great elevation in the present case obviated that objection. With regard to the support of the piles as fenders for steamers of great length coming alongside, he could quite enter into the feelings of the Author, who had no doubt adopted an ingenious and effectual mode of bracing the timbers. Some under his own supervision, where there was a rise of tide of 20 feet, the depth being 6 feet at low water, projected a considerable height above high water. They were isolated Memel sticks, and had been standing for thirty years, with powerful guy rods in front, mooring chains attached, and only two piles at the back, half the height of the front piles, with a diagonal, horizontal, and raking system of braces. He thought the arrangement adopted by the Author was a very good one.

Mr. Gilbert Redgrave said it appeared the original surface of the ground had to be largely made up in order that the goods and passenger station might be erected, and the Author had described

Digitized by Google

the difficulties experienced in building a great length of river wall, part of it in a considerable depth of water. The site was on a piece of land which might be taken to be nearly square. What then would be the objection to making tidal docks in lieu of an expensive river wall? Various sidings could have been brought alongside the docks, and the necessity for providing hydraulic machinery, and the rather complicated passages for loading and unloading, would have been avoided. The difficulty with reference to taking the passengers underneath the goods station would not have arisen, and the cattle and passenger traffic could have been kept wholly separate. The cost of constructing such docks would have been much smaller, he thought, than that of the river wall, and instead of being able to utilise only one side, vessels could be approached from all round. It would be interesting to have some further particulars respecting the deposit of concrete in bags. He wished to know whether the bags were sewn together, or made up in any way before they were placed. It would seem, if the bags were made whole, that after they were deposited the junction between two bags would have caused a line of imperfect jointing between the concrete, and so have given rise to difficulties.

Sir J. HAWKSHAW, Past-President, observed that he had not seen the site of the works, and he would not therefore suggest different arrangements in regard to the making of docks, or other matters which could only be well understood by those who had considered the case in point for a long time. He might say, generally, that any observations from persons called upon at a few minutes' notice to give opinions upon works of that sort, other things being equal, could not have the same authority as those of the engineer who had had to carry out the works, and who had therefore necessarily carefully considered his scheme. The Author had given, as might be expected, an intelligent account of an interesting work, and had brought two or three facts before the Institution which it would be useful to consider. With regard to the deposit of concrete in bags, there was no such difficulty as Mr. Redgrave apprehended. The operation had been carried out pretty extensively, and had been described before by Mr. Dyce Cay,[1] who, at Aberdeen, had deposited bags of concrete to a considerable extent. He had himself used concrete in bags, and had found no difficulty with reference to the jointing. If the bags were not quite filled nor the concrete made too hard, they were easily adjusted by divers, and by other processes, so that they could be packed close

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxix., p. 131.

Digitized by Google

together, and made very solid work. A curious illustration occurred in Holland some years ago. A sailing vessel laden with bags of cement foundered close to the Dutch coast; at low water she was got at, but it was two or three weeks before there was an opportunity of reaching the cement. The bags were taken carefully on shore, when it was found that the Portland cement in every bag had become solid and assumed the precise shape of the bag, representing almost every thread of the canvas which enveloped it, not only the weft but the woof could be traced, and the whole had to be broken up, and was used for macadamising a road. The water had percolated into the cement, which had become quite hard. This showed what could be done by using concrete in bags. There was no doubt that in many places it was an excellent method, and might be employed with effect. He thought that Mr. Barton had used it with judgment. With reference to putting concrete through water, he did not know how it was that Mr. Barton's effort had failed. He had put concrete through water in one case 70 feet deep. It required, however, two things: first, that the water through which the cement was put should be still, and excluded from the surrounding water; and, secondly, that the concrete should be made richer than usual, because it was necessary to allow for waste, which no doubt rendered it rather expensive. If the space could be inclosed, so as to prevent the water from flowing in and out, concrete could be sunk through water with perfect success. The southern end of Cannon Street bridge had been thus founded upon concrete. In that case square water-tight caissons were made, and the water being still, the concrete was lowered through it, and formed a sound foundation. Some of the cylinders in the Londonderry bridge had been treated in this way. In the case under discussion, perhaps the water was not perfectly still, and the cement might not have been quite sufficient. In the Mediterranean, walls had been built in that way for centuries, as might be seen at Genoa and Leghorn. The quay wall was divided into compartments; the space was lined with canvas; and white lime, which was obtained in the district, was mixed with pozzuolana only—no sand—and passed through water. Mr. Barton might probably have had recourse to large blocks with advantage. In some situations, walls might be built in that way with success. A remarkable instance might be seen at Dublin, where Mr. Stoney, who had read a Paper on the subject before the Institution,[1] had been using blocks 350 tons in weight. The

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxvii., p. 332.

Digitized by Google

work could not be well done in a rough sea; but under suitable circumstances the method might be adopted. A drawing of the dredger had not been given; but it must have been a good one to accomplish the work described. There was but a short time to work; and the difficulty of getting machinery to act when a vessel was oscillating in the waves was very great.

Captain CALVER said there was no question that the pressure of the ebb would be through the channel, and the only thing likely to diminish the depth in it would be a marginal, or littoral, drift across its outlet. If there were none, there was every chance of the depth being maintained without any expense.

Mr. BARTON, in reply, said that Cranfield Point practically extended underneath the water as far as Hoskyn Channel. The cut was not through a drift formation caused by the meeting of the ebb-tide and the current, the shoal was a part of the land, and, in fact, the action of the sea, for hundreds of years, had been to deepen the surface upon the bar. When operations were commenced there, the whole surface was coated with boulder-stones so close together that the action of the tide in deepening had evidently been stopped by them. They had accumulated gradually as the clay had been cut away, and had dropped down until they had formed a sort of armour over the surface of the bar. Cranfield Point above low water was itself wearing away by the action of the sea. Since the first cut had been made through the bar, three or four years ago, the action of the tide had been rather to deepen it. It had been always kept by the tide quite clear, and the soundings made from year to year had not shown any shallowing. The blocks in front of the quay wall had been more expensive than the bags of concrete at the back; not, however, in themselves, they were made in frames, and the cost of lowering them had been much the same as that of lowering the bags, but they had to be carefully set by divers, and on that account were more expensive. The expense of divers, where each stone had to be set, and inequalities to be removed, was a serious matter. He was inclined now to think that the bags might have been also used for the front, and in any similar case he should probably use them. The end, however, was much exposed, and on that account, and on account of the current, the large blocks were needed at that part. The velocity of the current at the entrance was about 4½ knots, and it varied throughout the whole of the district from 4 to 5 knots. Through the old channel it was not so much. The fenders occasioned some difficulty, inasmuch as the landing-stage had to be left free to move up and down in an open space, a steamer would come alongside

Digitized by Google

against a fender unsupported to the extent of 20 feet: that difficulty had been met by making box beams with $\frac{3}{4}$-inch plates and heavy angle irons—three in the width of the paddle-box, and braced together with a series of horizontal and diagonal wrought-iron box beams. As to the question of tidal docks, the whole object of the arrangement at Greenore had been for the purpose of establishing a fixed hour daily steamboat service, which was of immense importance both for passengers and for cattle traffic; so that tidal docks would have been out of the question. The cattle trade from Ireland was very large. The development of the trade between Holyhead and Dublin had proved how enormously a trade would increase when there was a fixed hour service on which dependence could be placed. There was a nightly steamer from Greenore to Holyhead; the second year's traffic had been 50 per cent. more than the first year's, and every department of the trade was rapidly increasing.

The bags held the concrete pretty loosely; the bag was put into a wooden skip, and the concrete came from the mixer direct: the flaps of the canvas were brought across the top and sewn with a packing needle, in a minute or two; the skip was then lowered and the bag was let out.

Mr. Stephenson, President, observed that there were several localities as well adapted as Greenore for the coasting trade of the country. He agreed with Sir John Hawkshaw in thinking that Greenore Harbour was an exceedingly useful one, both as a commercial harbour and for the smaller coasting vessels. He thought that the current through the new cut ought to be considerably faster than that through the old channel; if so, the chances of silting must be less. If Mr. Barton could get a little more money to make it 5 or 6 feet deeper, it would enable vessels of 500 or 600 tons to run in at low water. A vessel drawing 10 feet of water would strike in 3 fathoms in a heavy sea, so that the place could not be a harbour of refuge for large vessels. He would also suggest that a light should be placed at the entrance of the channel, as it was a dangerous thing to attempt to hit the channel by running in with two lights in one inland. If that improvement were carried out, and the channel deepened, the harbour would be one of the best on that part of the coast.

Mr. W. D. Cay remarked, through the Secretary, that the Author had successfully built part of the rear of the quay wall with liquid concrete in bags. He trusted, however, that the remarks in the Paper, as well as those of Sir John Coode on the New

Digitized by Google

South Breakwater at Aberdeen,[1] were not made with the view of appropriating for the Author the credit of originating the idea of constructing submarine works with liquid concrete in bags. The idea was not of recent date, having been described in the specification of a patent (No. 4,710) granted to James Frost, a builder, of Finchley, Middlesex, in 1822, for "A new method of casting or constructing foundations, piers, walls, &c.," from which the following was an extract, viz.: "In constructing foundations, and walls, and piers, the parts of which may be under water, I mix the required cement with the before-mentioned hard and durable substances; I enclose the composition in bags lowered by tackle to the surface of the work, and there dispose them in a regularly stratified manner while the composition is in a soft state, and will take the impression of the preceding layer in strata, and thus form courses of a well-imbedded conglomerate rock." He believed his own employment of the system at Aberdeen to have been as nearly as possible contemporaneous with its adoption by the Author, the experimental bags, the success of which led him to use the system, having been deposited in June and July 1870, and the active use of the bags having been carried out in the spring of 1871. Further, the system, described in the discussion on the Aberdeen Breakwater, of depositing concrete in bags by means of a hopper barge, had proved satisfactory and economical; nearly 9,000 cubic yards having been deposited in that manner during the latter part of last summer at the North Pier Extension Works, Aberdeen, mostly in 50-ton bags, at a cost of 21*s.* per cubic yard for labour and materials; and the power of the work so built of resisting the sea appeared in this case to be greater than if it had been built of ordinary prismatic solid blocks of similar weight.

Mr. P. J. MESSENT remarked, through the Secretary, that he commenced using concrete in bags placed by divers under the foundation blocks of the walls of the North Pier at Tynemouth in 1865. He first, unsuccessfully, tried mixing concrete in a diving-bell. Then, having noticed some bags of cement caked into solid masses from having been accidentally wetted at sea, he tried the concrete in bags. In the first experiments the materials were mixed and filled into the bags dry, but on examining them it was found that they had sometimes caked on the outside before the water got to the middle. Afterwards the concrete was mixed and watered before being put into the bags. The proportions were

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxix., p. 158.

Digitized by Google

about 6 of gravel and sand to 1 of Portland cement. He had since used concrete in bags very extensively. When the great accident occurred to the piers from the violent storms in December, 1867, the repairs, both temporary and permanent, were largely carried out in this way by filling the hollow spaces in and under the hearting with concrete in bags placed and packed by divers.

Digitized by Google

February 15, 1876.

GEORGE ROBERT STEPHENSON, President,
in the Chair.

No. 1,420.—"On Estimating the Illuminating Power of Coal Gas. By WILLIAM SUGG, Assoc. Inst. C.E.

NOTWITHSTANDING the attention which, almost from the commencement of gas-lighting, has been bestowed upon this important subject, yet gas photometry is still in an unsatisfactory state. With even the most perfect apparatus, the same quality of gas is differently estimated in various places, because there is no generally recognised standard burner. There is, consequently, a want of uniformity in the results of different operators, which inclines those who are not conversant with the subject in all its bearings to distrust photometrical tests, and to despair of obtaining more than an extremely rough estimate of the amount of light-giving power of any sample of coal gas. This applies with greater force, at the present time, to the estimations made by the public examiners than to those by gas-makers.

Since the elaborate series of experiments carried out by Mr. T. N. Kirkham, M. Inst. C.E., Engineer-in-Chief of the Imperial Gas Light Company, assisted by the Author,[1] gas-makers have been in possession of reliable means for their purpose.

One of the results of these important experiments is that the jet-photometer, originally invented by the late Mr. George Lowe, M. Inst. C.E., has been so improved, through the data thus obtained, that it is possible to ascertain by simple inspection the true illuminating power capable of being evolved from different coal gases. Thus, the manufacturers of gas are able to satisfy themselves reasonably well of the illuminating power, and consequently of the commercial value, of what they sell; whilst the public are not so well able to appreciate at its proper value the gas they buy, the jet-photometer not being a parliamentary test, and so not being used by the public gas examiners. This is probably the reason of much of the dissatisfaction expressed by the public in England and in other parts of the world relative to the gas supply.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 440.

Digitized by Google

The official certificate given in terms of the parliamentary standard candle, and of the various standard burners, does not always show the real light-giving power of the gas, neither does it appear to convey a sufficiently clear idea of its monetary value to those, unacquainted with gas photometry, who have to pay for it. The Author feels confident that this state of things may be altered, and satisfactory results obtained, by a modification of the apparatus at present in use for the purpose.

It is generally acknowledged that the most accurate way of estimating the illuminating power of gas is by burning a known quantity of that gas in a standard burner, and comparing the light with that from a known quantity of oil or sperm consumed in a certain kind of lamp or candle.

In England, since the year 1852, the parliamentary standard of comparison has been a sperm candle, of six to the pound, burning at the rate of 120 grains per hour. As the result of an elaborate series of experiments conducted by Professors Graham, Brande, J. T. Cooper, and Dr. Leeson in 1852,[1] it may be stated that the average normal rate of burning of these candles is nearer 130 grains than 120 grains. Therefore it is desirable that the parliamentary standard rate should be altered, if a change can reasonably be made.

The greatest obstruction to the adoption of a uniform system of gas photometry has always been the difficulty of settling the kind of burner through which the gas to be tested shall be burned. With the standard quantity of the same gas, different kinds of burners give varying results; and the same burner gives dissimilar results with an identical quantity of gases of different illuminating powers, richer or poorer, according to the quality of gas it has been originally designed for. Thus, as an example of the first difficulty, in 1863 Dr. Letheby found that seven 15-hole standard burners, provided with 7-inch chimneys, gave, for a consumption of 5 cubic feet per hour of the same gas, varying powers of light from 11·30 to 13·56 candles, or a range of 20 per cent. Yet these were all eligible as testing burners, because they agreed with the extremely vague description of the standard burner in the Metropolis and other Gas Acts, the wording of the Acts being generally, "a 15-hole Argand burner provided with a 7-inch chimney." As an example of the second difficulty, the present standard burner for the City of London does not, when made to burn a constant

[1] *Vide* Report of the Great Central Gas Consumers' Company's Arbitration, 1857, pp. 223–232.

Digitized by Google

quantity, develop the illuminating power of more than one quality of gas. Thus, if it be supplied with 5 cubic feet per hour of 16-candle gas, it will burn it very well, and give nearly true results; but with 5 cubic feet of 17- or 18-candle gas it ceases to do so, although it would succeed with a proportionately less amount of the richer gases. The reason is that the air and gas passages are arranged to burn 5 cubic feet per hour of 16-candle gas: richer gases, therefore, cannot get enough air for their proper combustion, and so the burner does not educe the full amount of light these gases are capable of evolving.

If gas is to be tested by the amount of light attainable from an unvarying rate of consumption of 5 cubic feet per hour, then it ought to be a *sine quâ non* that this standard quantity be as properly burned as a consumer can burn it. To do this not one only, but several standard burners are required. To Dr. Letheby belongs the credit of having made one of the first important steps towards an accurate estimation of the illuminating power of coal gas, for upon finding the great differences which existed in so-called standard burners, he, in the year 1863, designed, in conjunction with the Author, a standard burner with a 15-hole incorrodible steatite top for 14-candle gas. Previous to this all official testing burners had iron tops, which were subject to alteration by oxidation. With this burner the gas supplied to the City of London was tested until the appointment of the referees under the Metropolis Gas Act of 1869. Dr. Letheby was the first public examiner who introduced arrangements in the photometrical instruments for cutting off reflected light from walls, ceilings, &c.

It must be said, however, in justice to Mr. George Lowe, that, being aware of the necessity for a proper standard burner, he, so far back as the year 1859, urged the Committee on the Chartered Gas Bill to adopt the first one made by the Author for 12-candle gas with a steatite top and 15 holes; but his proposition was successfully opposed. The burner adopted by Dr. Letheby, known as the "Sugg-Letheby" 14-candle burner, is one of the parliamentary standard-testing burners for 14-candle gas, and is used with a chimney 7 inches long and 2 inches wide, in England, in some parts of North and South America, in Canada, Australia, and New Zealand. There are, however, two other parliamentary burners for 14-candle gas, viz., one described in the Birmingham and Staffordshire Gas Act of 1864, for testing the gas supplied to Birmingham, and also adopted at Hanley, Hull, and, till lately, at Brighton. It is of the 15-hole class, and is used with a similar chimney to the preceding one; the top is of hard bronze; but it

Digitized by Google

is equally unsuitable for ordinary use or for a testing burner. The other 14-candle burner is that adopted by the Gas Referees for London in 1869. The words of the Act (City of London Gas, 1868) under which the referees were appointed are with respect to the standard burner: "Section 43. The Gas Referees shall prescribe the burner for testing the illuminating power of the gas, and it shall be such as shall be the most suitable for obtaining from the gas the greatest amount of light, and be practicable for use by the consumer."

This burner, the invention of the Author, is known as Sugg's "London" standard Argand burner for 14-candle gas, and is used for testing the gas supplied to the City and other parts of London by the Gas Light and Coke Company, by the Imperial and South Metropolitan Gas Companies, and by a number of companies in the provinces. It is also the new standard burner for the Dominion of Canada, and the Author believes for New York, Philadelphia, Chicago, and some few places on the Continent of Europe.

The same standard quantity of the same quality of gas tested by these three burners shows very different powers of light, the "London" burner evolving the greatest, and the Birmingham the least amount of light. The total difference is nearly three candles.

There are three different parliamentary standard burners for testing 16-candle gas, all to consume the standard quantity of 5 cubic feet per hour, viz., the "Dublin" 16-candle Argand 15-hole steatite-top burner, used with a chimney 7 inches long by 2 inches wide, specified in the Dublin Gas Act. This is a modification of the "Letheby" burner, the only difference being that the central aperture for the admission of air is larger than in the "Letheby," the richer gas requiring more air for its combustion. The Dublin flat-flame 16-candle burner, specified in the Dublin Gas Act of 1873 to burn 5 cubic feet of gas per hour under a pressure of 0·5 inch. And the "London" standard Argand for 16-candle gas with a 24-hole steatite top, to be used with a chimney 6 inches long and 2 inches wide. The last is the same as that adopted by the Gas Referees for testing 14-candle gas, the only difference being in the increased diameter of the chimney.

The Gas Referees likewise direct in their instructions to gas examiners, with a view of getting a more nearly correct estimation of the power of richer gases than 16-candle gas, that in the event of the flame from the standard quantity tailing over the 6-inch chimney a 7-inch one is to be substituted for it.

At the time the referees were called upon to prescribe the

Digitized by Google

standard burner for 16-candle gas, no other of that kind existed than the Dublin burner, which does not comply with the requirements of Parliament, inasmuch as it is not the best burner for the use of the consumer, neither is it a good testing burner. The standard quantity of the same quality of gas affords different degrees of light with each of these three burners. The London burner gives the greatest, and the Dublin "Argand" burner the least light. The total difference varies from about $1\frac{1}{2}$ to $1\frac{3}{4}$ candle.

There is but one parliamentary standard burner for consuming 5 cubic feet per hour of 18-candle gas, viz., that described in the Leamington Gas Act, which is a modification of the "Sugg-Letheby" burner, the central aperture being enlarged to supply more air to the richer gas. It is not much used, and is not the best burner for the consumer. The difference in amount of light given for the standard quantity of the same quality of gas consumed in the "London" 18-candle burner and the Leamington burner is about $2\frac{1}{2}$ candles; the "London" burner yielding the greatest, and the Leamington the least light. For 20-candle gas the parliamentary standard burner is described by the Gas Referees as Sugg's steatite batwing, No. 7. It is used in London and in Liverpool. There is another which is described in the Dublin Gas Act, and which it is specified shall consume 5 cubic feet per hour at a pressure of 0·5 inch of water at the point of ignition. The difference between this and Sugg's steatite, No. 7, is $2\frac{1}{2}$ candles with 20-candle gas.

The Argand burner is erroneously supposed not to yield so good a result in burning 5 cubic feet of Cannel gas as the batwing burner. For 27- up to 32-candle gas, it is customary, in Scotland and elsewhere, to make use of any kind of fish-tail burner, and to consume any quantity of gas, at the option of the operator. For Cannel gases there is no regularly authorised parliamentary burner, neither does it appear that custom has established one which might serve the purpose; so there is great uncertainty as to their true illuminating value.

From what has been stated it will be readily perceived that a revision of the standard-burner system is greatly needed. Evidence has been given, and probably will again be given, in Parliament relative to the cost of gas, which is absolutely enigmatical, excepting to those who are well versed in the question of standard burners. Now if the standard burner were equally certain as a standard pint measure, so that it might be regularly stamped by the Standards Department of the Board of Trade, it would be known that 14-candle or 20-candle gas meant such a quality of gas that

Digitized by Google

a consumer could, if he pleased, obtain from the combustion of 5 cubic feet of it a clear white light equal to fourteen or twenty sperm candles of six to the pound. But the success of those appointed to settle the question of standard burners has been very indifferent.

Naturally it will be imagined that the illuminating power of gas is the light it can be made to evolve. Such a starting point was for the first time agreed upon by the Engineer to the Corporation of the City of London, Mr. William Haywood, M. Inst. C.E., and Dr. Letheby, in their joint "Report to the Special Gas Committee of the Commissioners of Sewers," dated the 10th of December, 1864. In giving the reason for the adoption of the "Letheby" burner for testing purposes, they state,[1] that "as no burner can produce light, but merely educe it, they (the gas companies) are entitled to all the light which can be evoked from the gas by any burner which fulfils the conditions of the Act of Parliament." This, at that time novel view of the case, was after careful examination confirmed by Mr. Cardwell's committee on the Metropolis Gas Bill of 1868. Since then the only standard burners which have been adopted are the Gas Referees' (London) 14- and 16-candle burners, and the Dublin flat-flame burner, which is only used for testing the gas supplied to the city of Dublin. All others were adopted before this principle of selection had been agreed upon.

Now it is evident that, as the guiding principle recommended by Mr. Cardwell's committee will influence the selection of standard burners for the future, there must be as many standard burners as there are different qualities of gas, supposing all are to be tested by burning a uniform quantity of 5 cubic feet per hour. Such a system will take much time to perfect, and will require great care on the part of the gas examiner. In fact, he must know before he makes the test what is the light-giving power of the gas, so that he may use the right burner to develop its qualities. Strange as it may appear, there is no difficulty with a proper set of standard burners in arriving at this conclusion, by finding which of the standard burners will burn the required 5 cubic feet of gas per hour giving a flame of, say, 3 inches in height. If, for example, the 16-candle standard burner will do this, then the gas is equal to sixteen sperm candles, and the subsequent test will only be a corroboration of the fact.

But the system invented by the Author is much simpler than that. One standard burner only is proposed for all qualities of

[1] Page 64.

Digitized by Google

gas from twelve to thirty candles. This burner may be readily gauged and verified by actual trial against the Government standard burner, as in fact the Gas Referees' London standard burners are now verified. The burner which the Author proposes as the standard burner for all gases is the Gas Referees' London Argand burner, with a chimney 6 inches or 7 inches long by $1\frac{3}{4}$ inch wide, producing a flame always 3 inches in height. To enable it to burn with a steady flame a slight modification must be made. This will then be the same kind of burner which is ordinarily adopted by consumers.

When used with 16-candle gas it will burn 5 cubic feet per hour with a 3-inch flame, the light from which will be equal to that given by sixteen sperm candles of six to the pound.

The following table shows the quantities of different qualities of gas required to produce in burning a 3-inch flame with this burner, viz.:—

With	12-candle	gas it requires	6·65	cubic feet.
„	14	„ „	5·72	„
„	16	„ „	5·0	„
„	17	„ „	4·7	„
„	18	„ „	4·4	„
„	19	„ „	4·2	„
„	20	„ „	4·0	„
„	25	„ „	3·2	„
„	30	„ „	2·6	„

Of late years a Gas Referees' standard burner has been constantly used by the Author as a standard light for testing various kinds of gas burners, and it has been found that the illuminating power, as well as the appearance of the 3-inch flame, has been always constant, notwithstanding considerable variations in the quality of the gas. On several occasions it was tried with two different gases, one quality of gas being equal to thirteen candles and the other to twenty candles; but the most careful observation failed to detect the slightest variation in the amount of light given by the standard 3-inch flame. Only the quantity of gas supplied to it was gradually lessened, and the pressure at the foot of the burner was proportionately diminished as the richer gas displaced the poorer, and *vice versâ*.

For the convenience of gas examiners, the Author has prepared a table showing the illuminating power of gases, the quantity required to give a 3-inch flame to this burner having been ascertained.

This system of a constant flame is founded on the jet-photo-

Digitized by Google

meter system explained in the Paper on "Experiments on the Standards of Comparison employed for Testing the Illuminating Power of Coal Gas,"[1] by Mr. T. N. Kirkham, and also upon the old Scotch duration test invented by the late Dr. Fife. These systems are combined with the present parliamentary system of ascertaining the illuminating power of gases by comparison with the light of the flame of a sperm candle. The proposed method of effecting this is as follows:—The Gas Referees' 3-inch flame burner having been fixed on a photometer in the place usually occupied by the standard burner, it is to be lighted, and allowed to burn off all the dead gas collected in the meter and fittings of the apparatus. Then, a clean chimney is to be put on, and the height of the flame regulated by the aid of the usual micrometer cock and King's pressure gauge to exactly 3 inches. The quantity of gas per hour required to give this flame is then to be found, and a reference to the table will show the examiner the illuminating power of the gas. The rest of the experiment is performed in accordance with the instructions of the Gas Referees. The result is the illuminating power of the gas in terms of the parliamentary standard quantity of 5 cubic feet of gas and 120 grains of sperm candle. Every quality of gas tried upon this system will be fairly consumed, and a like quantity of gas will be designated by the same number of candles of illuminating power.

In conclusion, it must not be supposed that because there will sometimes be a divergence between the illuminating power as found by the candles, and that indicated by the Author's table, the system here described is uncertain or variable. The steadiness of the standard light enables the examiner to detect the variations in the illuminating power of the sperm candles, which he was not previously able to discover. A reference to Mr. Kirkham's experiments[2] will demonstrate to which of the two, candles or standard flame, the discrepancy, if any, is to be attributed.

---

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 440.
[2] *Ibid.*, vol. xxviii., pp. 443–447.

[Mr. Sugg

Digitized by Google

Mr. Sugg said since the Paper was written, he had combined the whole of its recommendations in an instrument, in which the dial was divided off so as to show the quantity of gas required to give a light equal to any number of sperm candles up to sixteen. A burner was fixed to it which, when the flame was exactly at the height of 3 inches, gave always a light equal to sixteen sperm candles. The quantity of gas required to produce light of that intensity would vary according to the quality of the gas, and was shown in the tables.

Dr. Letheby remarked, through the Secretary, that Mr. Sugg had done good service by bringing this important subject before the Institution, with a view to discussion; for it must be admitted that the present means, and parliamentary provisions, for estimating the illuminating power of coal gas were, as Mr. Sugg said, in an unsatisfactory condition. He might add, indeed, that this was not only the experience of practical men like Mr. Sugg, and the gas-testers appointed under various Acts of Parliament, but it was also seen in the difficulties and disputes which were constantly arising whenever gas companies and local authorities were in conflict, as was too often the case, on the question of the illuminating power of the gas supplied to the public. These difficulties began about the year 1848 or 1849, when at the instance of three distinguished chemists who had passed away, namely, Professor Graham, Dr. Leeson, and Mr. Cooper, the Great Central Gas Consumers' Company adopted, under severe obligations, a parliamentary standard of illuminating power, and a prescribed method of determining it, the standard being an illuminating power of twelve wax candles of six to the pound, each consuming 120 grains of wax per hour, and the gas was to be burnt at the rate of 5 cubic feet an hour from an Argand burner of fifteen holes and a 7-inch chimney. It happened that he was the officer appointed by the Corporation of London in 1850, under the provisions of the Great Central Companies Act, which had just become law, to test the quality of the gas supplied to the city, and to see that the obligations of the company were duly fulfilled. This was the first appointment of the kind that was ever made; and he soon found that all the provisions of the Act for estimating the illuminating power of the gas were radically unsound and unreliable; in fact, the whole subject of gas photometry was in a crude and imperfect condition, and he felt that it must be reformed from end to end. The wax candles, for example, prescribed by the Act, were among the worst sort of candles that could be used for photometrical purposes; and the reason was obvious, for as a wax candle, like a common tallow

Digitized by Google

candle, required snuffing, and grew dimmer and dimmer as the head of carbon accumulated upon the wick, it was a difficult question to decide when that delicate operation of snuffing should be performed. One of the first things, therefore, which he did was to rectify the standard candle; and after about one thousand experiments for the purpose of determining the relative illuminating power of wax and sperm, he adopted the latter, using a plaited wick which snuffed itself. This had been the standard candle from that time to the present, for it was adopted by Parliament in 1852. He moreover used two candles instead of one, in order that the light might be intensified, and the rate of combustion equalised. This also had become the practice in photometry. After a time, however, the sperm candle became a subject of perplexity, from the circumstance that during the American war, when long-fibre cotton was difficult to obtain, a short-fibre cotton was used in the construction of the wick, and thus the combustion of the candle became irregular. More recently, in consequence of the increasing value of spermaceti, the candle was frequently adulterated with paraffin and stearic acid, so as to be untrustworthy as a photometrical standard. There was a want, therefore, of a radical improvement in this particular. In the next place, the photometer was a very imperfect instrument, with reflecting surfaces, and with the Bunsen disc exposed on both sides to extraneous light. This he remedied by the use of screens, and by inclosing the disc in a chamber or camera, which only permitted the access of the direct light from the gas and the candles, as was seen in the photometer which bore his name. The burner also, which was described in the Great Central Company's Act as an Argand of fifteen holes with a 7-inch chimney, was so constructed by different makers as to give, with the same gas, when burning at the same rate, an illuminating power that ranged from about ten to fifteen candles. This was caused by the want of uniformity in the size of the apertures through which the gas escaped from the burner, and in the diameter of the hole through which the air passed to the interior of the flame. There was not, in fact, at that time the slightest provision for the proper adjustment of air to gas; and therefore, with different burners, of Act of Parliament quality, the photometrical results were most discordant. Very little experimental inquiry showed that the smaller the apertures, and the higher the pressure at which gas issued from the burners, the lower was the illuminating power; and, on the other hand, the larger the hole which gave access of

Digitized by Google

air to the interior of the flame, the lower also was the illuminating power. A careful examination of these facts by Mr. Sugg and himself led to the construction of the burner which bore their names, and which, until recently, had been the standard burner for photometrical purposes—the size of the internal hole being graduated according to the quality of the gas; and thus, with the assistance of perforated discs upon the gallery of the burner, the proper adjustment of air, and thereby the proper combustion of gas of different qualities, had been approximatively secured. More recently, however, the improvements of Mr. Sugg in the same direction had produced a still better burner, which was rightly proposed as the standard burner for general use. These improvements consisted, first, in the reduction of the pressure of the gas to a minimum at the point of combustion; secondly, in a well-regulated supply of air to the interior and exterior of the conical flame; and thirdly, in the adoption of means for keeping down the temperature of the burner, in order that the issuing gas might not be expanded by the heat of the burner. Possibly further improvements might yet be made in the construction of test burners, but sufficient progress had already been made to justify the proposition of Mr. Sugg, that his burner should be accepted as a standard instrument, so that litigation and trouble on this head might be in future prevented. And now came the important question—how was the burner to be used? Should it be, after the old Parliamentary fashion, of forcing 5 cubic feet of gas through it per hour, whether the burner consumed it properly or not, or should the quantity of gas necessary to produce a flame of given intensity or of given measurement be determined? It was, he thought, abundantly evident, that the present practice in this country of forcing 5 cubic feet of gas an hour through a burner, whether it would effectively carry this quantity or not, was radically wrong; for with any given burner and chimney, suited for the proper combustion, and full development of the illuminating power, of that quantity of gas, it must be that when gas of inferior quality was passed through it at the same rate, the gas would be over-oxidised, and therefore made to appear of less illuminating power than it really was. On the other hand, superior gas would be under-oxidised, and would escape as smoke without developing its full value. This was actually the case with the Birmingham burner referred to, which, at the time of the passing of the Companies Act in 1864, and at the request of the Parliamentary Committee, he designed, in conjunction with Mr. Bowditch, as the standard burner for

Digitized by Google

14-candle gas. They were compelled to use a metal top, in accordance with the instructions of the Committee; for the Corporation of Birmingham, who were in opposition to the gas company, would not have a burner with a steatite top, and this they would now regret, having lately purchased the works of the company. This burner was exactly suited for 14-candle gas, but if the gas were better or worse than this, the burner would do it injustice. The same was the case with other standard Argand burners, as the Dublin, Leamington, &c., which had been constructed on their principles; and therefore, if Parliament insisted on the passing of 5 cubic feet an hour through a test burner, the gas companies should be permitted to select that burner which, while fulfilling the conditions of the Act of Parliament, developed the illuminating power of the gas to the fullest extent. It was far better, however, that the second alternative should be resorted to, namely, the use of a standard burner, like a standard measure, as Mr. Sugg proposed, and the determination of the quantity of gas to be passed through it, so as to develop a flame of standard intensity or standard height. The intensity of the flame might be measured, as was the practice in France, under the advice of Dumas and Regnault, by keeping it exactly equal in illuminating power to that of an Argand burner, of prescribed conditions, consuming a given quantity of colza oil. Or it might be measured, as he had proposed, by ascertaining its penetrating power in passing through a medium of given opacity—say a piece of dark bottle glass cut in wedge shape. But if the height of the flame were the test, nothing was easier than to fix on such a height as would be best suited for the maximum development of light, and then to determine the quantity of gas per hour necessary to produce such a flame. Long ago, the late Dr. Fife showed that the quality of gas, as regarded illuminating power, might be determined by burning the gas from a jet of given dimensions, and observing the rate of combustion necessary to produce a flame of given height, or by observing the height of the flame when the gas was burnt at a given rate. Under the name of Lowe's Jet Photometer, the last method was practically in use at gasworks for the purpose of ascertaining the quality of the gas as it was made; and there was no reason why the other plan might not be pursued, for the principle was manifestly correct.

The illuminating power of gas was dependent on the proportions of the rich and heavy hydrocarbons which the gas contained; and as these were of much higher specific gravity than the hydrogen

Digitized by Google

and marsh gas, which were the chief constituents of coal gas, it was evident that the density or specific gravity of the gas would rise in proportion to the quantity and quality of the hydrocarbons contained in it. Now, the experiments of Dr. Fife, as well as the more recent investigations of Professor Graham, had shown that the flow of gas through a small orifice was inversely proportional to the gravity of the gas. A light gas, for example, would pass much more freely and easily through such an orifice than a heavy gas. The law, indeed, as expressed by Professor Graham, was that the velocity, or rate of flow, was inversely as the square root of the density. If, therefore, the flame were used as the exponent of density, as it really was in the case of the heavy hydrocarbons, its height under a constant rate of flow would determine the density or quality of the gas; while with a flame of a given height, the rate of flow would be the means of arriving at a like result. This was the principle which the Author had in view, and no doubt it was susceptible of practical application. His experiments, indeed, showed that this was the case, and that the results obtained by it were accurate and trustworthy. The simplicity of the process was, moreover, a great recommendation, as it was capable of being applied under all circumstances, without the complicated machinery at present in use; only a standard burner being required with a handy, portable, and accurate meter, together with a delicate thermometer and a good aneroid barometer.

Mr. VERNON HARCOURT remarked that he had not had an opportunity of seeing the apparatus previously, and therefore could not presume to offer an opinion upon its practical value. One or two points mentioned by the Author were of great interest, and one certainly which he had not previously understood, viz., that flames produced by different samples of gas at the same burner did not differ from one another except in size, and that provided the total surface of the flame was the same, whatever the quality of the gas burnt, the amount of light it gave was the same. That was certainly at variance with common observation as to coal gas. Remarks were often heard as to the apparent brilliancy of the light, which were intended to refer to the effect produced by a given area of flame upon the eye; but from what Mr. Sugg said he understood a 3-inch flame, from the same burner, would always give the same amount of light, whatever the quality of the gas. Another question suggested by the Paper was as to the reason why the size of the flame should vary, as it was known to vary, other conditions being alike, with the quality of the gas. One reason for this was the decomposition of the heavy hydro-

Digitized by Google

carbons at the high temperature of the flame. It was well known to chemists that at that high temperature these hydrocarbons were resolved into a larger volume of lighter gases. As soon as the gas had passed through the burner and had been heated part of it was decomposed, and a larger volume of gas was formed; so that actually with a richer gas, though the quantity passing through the meter was the same, the quantity in the flame was a larger volume, and therefore, to obtain a flame of a given length, it was necessary to burn less gas as measured by the meter. He did not understand why an Argand burner with a 3-inch flame was used, because, comparing the instrument with the jet-photometer, it appeared to have at least two disadvantages. It would seem an easy matter to determine the height of the flame, but actually its top consisted of a number of shifting peaks, and although it was possible to arrive at some rough average, yet its position could not be determined with accuracy. The error so produced appeared to be increased by using so short a flame. With a flame 6 inches long a small error as to the position of the top of the flame mattered less than in the adjustment of a 3-inch flame. The uncertainty as to the position of the top of the flame in the latter case was much greater, and the error caused by that uncertainty was greater. He could not understand why, in this instrument, such a flame was adopted, instead of the long flame with a well-defined top which was used in the jet-photometer.

Mr. Law said that portion of the profession engaged in gas engineering was much indebted to Mr. Sugg for the attention he had given to the subject of the Standard Gas Burner. No doubt the burner he had introduced was that which gave the most uniform results, and without which the present perfection of gas photometry could never have been attained. The most imperfect part of photometrical apparatus was that employed as the standard by which the instrument could be perfectly adjusted. Whatever photometer was used—whether Bunsen's, or Wheatstone's, or the wedge—they all depended ultimately upon the estimation of the human eye; and not only did that estimation differ in different individuals, but in the same individual in different states of health or other physical circumstances. He had placed on the table an instrument which he believed would become the standard photometer, because it was entirely independent of the physical conditions of the human eye, and really measured the intensity of the light by the velocity of its revolution. It was a recent discovery of Professor Crookes, and seemed to presage some great discoveries in reference to those extremely attenuated media of

Digitized by Google

which Mr. Grove first showed the correlation, such as light, heat, magnetism, actinism, and electricity. The instrument was actuated by the intensity of the light. The cause of its revolution was not so important to inquire into in reference to this subject, but it was a fact that the velocity would vary according to the intensity of the light. It was most sensitive in its operation; it consisted of arms of aluminium with discs of talc, which were black on one side and polished on the other, and the influence of light upon it produced the revolution; it was in a perfect vacuum. The mode of making use of it would be to let it move at such a low velocity as would enable the revolutions to be counted; and the number of revolutions would determine the intensity of the light. If it were further improved by making one of the arms magnetic, a registering apparatus might be put outside, so that the number of revolutions might actually be recorded. In reference to the proposed mode of estimating the illuminating power of gas, he could speak from experience of the great value of having some simple mode which did not depend upon the estimate of the eye of different persons, such as in the Bunsen photometer; for he knew by experience, that fiscal engineers in foreign parts, not accustomed to this kind of observation, would estimate the gas at two or three candles different from the practised gas-maker who was used to the instrument.

Mr. Barlow, Vice-President, did not think Mr. Crookes' instrument had been presented in a form suitable for measuring light alone, because it was affected not only by light, but by heat. It would require some provision to exclude the action of heat, because the worst gas was that which gave much heat and little light; and the instrument would be caused to revolve by gas of inferior quality almost as much as it would be by gas of high illuminating power. Care would therefore be required to exclude the effect of heat, otherwise bad gas might be registered as good.

Professor Abel observed that Mr. Crookes had already given serious attention to that subject, and no doubt would be able so to arrange the apparatus as to shut off the rays of heat, and to obtain trustworthy records of the different illuminating power of the light emitted from different sources. He had sanguine anticipations of the results that Mr. Crookes would obtain in this direction. He had listened with great interest to Mr. Sugg's communication. The only point that occurred to him in reference to it was the one Mr. Harcourt had noticed, viz., the uncertainty of measuring the exact height of so short a flame.

Digitized by Google

Dr. POLE said it might perhaps be useful to state what was actually done in regard to testing gas, and the employment of burners in London. The ordinary method of testing gas was by means of the photometer, by putting a gas flame on one side of the disc and a standard candle on the other, and comparing the effect of the two in the usual way. Then the question arose as to what kind of burner should be used. Dr. Letheby had given a good historical account of what had been done with regard to burners, and Dr. Pole would take it up at about the point when the Act of 1868 was passed, which directed for the first time on a good scientific basis the testing of gas throughout London, and when a new clause was introduced with regard to the construction of the burner. It was not attempted to define what kind of burner should be used, but the clause left it to the Gas Referees to prescribe the burner: "The burner shall be such as shall be the most suitable for obtaining from the gas the greatest amount of light, and be practicable for use by the consumer." The illuminating power of gas varied immensely according to the burner used; it was supposed a sensible consumer would get the best burner he could, and the company of course had a right to have their gas tested by that burner. It came to the same thing as saying that the company should have their gas tested by the best burner which could be used by the consumer, and that was how the legislation stood at this moment. The Referees examined a great number of burners, and chose the one called Sugg's Standard London Burner as answering that condition; and that it had been used by the public was proved by its large sale. It also gave a pretty high illuminating power to the gas tested by it. It was prescribed by the Gas Referees and had been in use ever since, being considered a very good burner.

Then came another question, the quantity of gas passed through the burner; and here it was found that the same burner would give different results with gas of the same power according to the quantity which passed through it. Thus 5 cubic feet an hour passed through a burner would give one result, but if in the same burner only $2\frac{1}{2}$ cubic feet an hour were burnt it would not give the same proportionate result as before. He had occasion to go into the cause of this some time since, and found a curious law applicable to burners generally. It was expressed by the equation

$$L = m\,I\,(q - c).$$

Supposing L to be the light given off by the flame of a burner,

Digitized by Google

I the illuminating power of the gas, and q the number of cubic feet of gas burnt, per hour; m and c were two constants, and that equation would give for all burners he had tried the light given out by burning a certain quantity of gas. The values of m and c came out as follows. For Argand burners generally m varied, according to the goodness of the burner, from 0·2 to 0·33, and c was pretty nearly 2. For flat-flame burners m varied from 0·1 to 0·2, and c was about 0·5. The inference was, with whichever burner, that the more gas burnt in the burner—that was, up to its maximum power, so that it did not smoke—the better was the result obtained. That led to this, that since the burner ought to burn the gas to the best advantage, it was necessary to have the flame pretty high, and the standard London Argand was made so as to burn about 5 feet an hour without smoking. That was how the burners used in testing gas in London had been arranged. Then came this difficulty. The gas of course varied in power; no gasworks could keep their gas always of the same strength; sometimes it was a little less than at other times, and sometimes more. When the illuminating power of the gas increased there was a tendency to smoke and flare above the chimney, and that had to be corrected. The examiners could not alter the quantity, because the Act mentioned 5 feet an hour; all they could do was to check the smoking by putting on a different chimney, which did the gas harm. On the other hand, if the power of the gas diminished, then the burner was not doing its best, as the flame became too low. Now, without going so far as Mr. Sugg had done by changing the plan altogether, the liberty of altering the quantity would, he thought, be a great convenience; when the gas became of a higher illuminating power, the quantity could be reduced, and when it had a lower illuminating power the quantity could be a little increased. This would have another advantage, inasmuch as it would represent more nearly what the public did. The public, in using the gas, kept the flame at pretty nearly the same height, and if the gas was too rich, rather than have it smoke, they turned it down, or if it was too poor, they increased it. Hence, the power of varying the quantity in testing the gas, according to the illuminating power, would in reality correspond to the ordinary conditions of practical use, one of the objects aimed at by the legislature.

Dr. Pole then referred to the late discoveries of Mr. Crookes, particularly as to the possibility of measuring the intensity of light by its mechanical radiating force, and he described, at some length, the several ingenious methods by which Mr. Crookes, in a paper

Digitized by Google

lately read before the Royal Society,[1] had shown how the intensity might not only be accurately measured, but automatically recorded. He did not assert that these instruments were at present in a position to be used for a photometrical purpose of the importance of gas-testing in London; but Mr. Crookes' discoveries contained the germ of a great improvement, which might one day be of considerable value.

Mr. J. N. DOUGLASS considered there must be some mistake on Mr. Vernon Harcourt's part as to the power of the flame being due to its length. He did not think Mr. Sugg could mean that a flame 3 inches long, giving a light equal to sixteen candles, could not be shortened without impairing its intensity. In lighthouse burners it was desirable to confine the length of the flame, and indeed to obtain a flame nearly spherical, for the purpose of utilising it more completely by the optical apparatus; and he had found that such a flame as that of the Sugg burner could be reduced to less than half its length, still retaining the same illuminating power. Nearly three years ago he had to apply, for the first time, Argand gas burners in the focus of parabolic reflectors for the Caistor leading lights at Yarmouth. He tried several gas burners, and among them Sugg's London Argand burner, which he found to be the best; but still the flame of this burner was too long for the purpose, it being about 1 inch in diameter and 3 inches in length. He therefore made some experiments, basing them upon the principles adopted in the improved "Trinity House" oil burners for obtaining perfect combustion and the required form of flame. He succeeded in arriving at the desired result, and also in attaining nearly the same economy in combustion as had been found in the improved "Trinity House" oil burners. On comparing the new one with the Sugg burner of the same dimensions and number of holes, the two consuming the same quantity of gas, viz., 5 cubic feet per hour, he obtained nearly 33 per cent. more light with the former. He submitted the burner to the Elder Brethren of the Trinity House and to their scientific adviser Dr. Tyndall, and took it to Mr. Sugg, who tested it with the same results, and who afterwards made the burners for the Caistor lights, which had been in use ever since. Mr. Sugg had since modified his London burner somewhat in accordance with the one referred to. The original London burner had a cone, but no central deflector or button, and there was no air passage between the cone and the glass chimney. The improved burner was the most perfect Argand

[1] *Vide* Proceedings of the Royal Society, vol. xxiv., p. 282.

Digitized by Google

burner he had yet met with for general lighting purposes. The use of inner and outer deflectors to Argand gas and oil lamps had been patented by Mr. W. Wilkins, in 1862–3. By the application of these deflectors, and other improvements to oil burners, he had found that with the present "Trinity House" improved lighthouse burners, which were adapted for burning either animal, vegetable, or mineral oils, when consuming colza oil the standard had been raised 39·38 per cent, *i.e.*, the illuminating power had been increased 22 per cent., with a reduction in the consumption of oil of 17·38 per cent. If considered economically, irrespective of the increased power per burner, a saving of oil had been effected of 32·47 per cent. These results were sufficient to show the importance of an efficient gas or oil burner. At the same time it could not be too clearly kept in view, in adopting a standard burner for estimating the illuminating power of coal gas, that as the efficiency of such a burner was improved the specified candle power of coal gas would be raised *pro ratâ*, otherwise the benefit to be derived by such improvements would fall to the gas companies instead of to the public.

Professor W. G. ADAMS observed that it had been pretty generally admitted, that the means of estimating the illuminating power of coal gas was in an unsatisfactory state. This was true of the power of measuring as well as of the power of producing the illuminating power; and all existing photometers were defective in that they relied on comparisons made by the eye of the observer between illuminations from two distinct sources. Attention had been drawn to another method of measuring the intensity of light by means of the radiometer, invented by Mr. Crookes, where the action of light and heat falling on a pith disc, which was blackened on one side, caused it to rotate, thus establishing a direct relation between two of the physical forces, radiant heat or light and motion. He wished to draw attention to the direct relation between two other of the physical forces, light and electricity, which was established by Mr. Willoughby Smith three years ago; who discovered that when light fell upon a piece of crystalline selenium which was in an electric circuit with a battery and galvanometer, the electrical resistance of the selenium was diminished by the exposure. During the last two years Professor Adams had been experimenting on this subject, and his results had been laid before the Royal Society.[1] They seemed to show that those rays of the spectrum which

[1] *Vide* Proceedings of the Royal Society, vol. xxiv., p. 163.

Digitized by Google

produced light were the rays to which chiefly, if not entirely, the change of electrical resistance was due. The dark heat rays produced little or no effect on the electrical resistance of the selenium. He had inclosed pieces of crystalline selenium in a box with a lid to exclude the light, the bottom of the box being made of ebonite, into which were fixed the binding screws for supporting the selenium, and making contact with the electrical circuit. The resistance of the selenium was balanced, before exposure, by a high resistance formed of a thick blacklead pencil mark on ebonite, which was varnished with a thin coating of shellac varnish. The spot of light of a delicate reflecting galvanometer was then at the zero of the scale. On opening the lid of the box the resistance of the selenium was diminished, and the spot of light travelled along the scale. Several series of experiments had been made to determine the relation between the intensity of the light and the change of resistance which it produced. The intensities of different sources of light had been compared by means of Bunsen's photometer, and the change due to the exposure to these sources had been determined by the throw of the galvanometer needle, the duration of each exposure being ten seconds. In one series of experiments, the action of a single candle placed at different distances from the selenium had been measured, and compared with the action of an Argand lamp of the illuminating power of sixteen candles. The following deflections of the needle were obtained:—

	At ½ mètre.	At ¼ mètre.	At 1 mètre.	At 2 mètres.
With the Argand lamp	..	170	83	39
With one candle . .	82	40	18	8

In another series of experiments, with a different piece of selenium exposed to the light of a single candle at varying distances, the results were:

	At ½ mètre.	At ¼ mètre.	At 1 mètre.
With one candle . .	45	25	15
„ „ . .	40	20	10

The results obtained showed that the action of the light during exposure for ten seconds, as indicated by the throw of the galvanometer needle, was inversely as the distance of the source of light, *i.e.*, directly as the square root of the illuminating power. Hence with the selenium photometer, when two sources of light at different distances produced the same change of resistance in the selenium, their illuminating powers were directly as the squares of their distances from the selenium. Not only might the relative illuminating powers of two sources of light be compared by this

Digitized by Google

photometer, but a direct relation might be obtained between the illuminating power of the light and the change of resistance produced by it in a given piece of crystalline selenium at a given temperature.

Mr. SUGG, in reply, said he had placed on the table the jet-photometer, to illustrate the difference between it and the Illuminating Power Meter, and that it might be seen how far the results corresponded in the manner mentioned by Mr. Vernon Harcourt. Dr. Letheby had referred to the variations in the illuminating power of the standard sperm candles. This subject had already been brought before the Institution in a Paper by Mr. T. N. Kirkham, M. Inst. C.E.,[1] in which the results were given of a great number of those experiments—especially of one series made in conjunction with Dr. Odling, and in which he found there was a difference ranging as high as five candles in the estimation of 14-candle gas. That arose in this manner: Dr. Odling purchased the candles in different places, and the difference in their manufacture was sufficient to cause the wide variation of five candles. Dr. Odling was quite satisfied at that time that the candles were not a reliable standard. By making them carefully that error had been mitigated; but it was still open to inspectors testing gas throughout the kingdom, except those testing under the Gas Referees, to buy their candles wherever they liked; and if those candles were adulterated with paraffin or stearine, there was sure to be a difference in the illuminating power. The object of the illuminating power of the meter was principally to have a check upon the candles; and he did not propose, as Dr. Letheby seemed to imagine, to do away with the ordinary photometric test, but simply to put, at one end of the photometer, his standard burner, which would always give a light equal to sixteen sperm candles, so as to check the candles if they did not burn properly. He had made a number of experiments with these candles in comparison with the standard burner, and found that the candles gave a different result, varying from 15 to 17; whereas the flame had always been supplied by the same quality of gas, and therefore there could be no variation. With respect to the Birmingham burner, Dr. Letheby remarked that, probably, now that the authorities had taken the matter of gas into their own hands, they would regret the adoption of the Birmingham standard burner for the purposes of testing the standard gas. At the present moment they had escaped from that difficulty by adopting the London

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 440.

Digitized by Google

Standard Burner; but in other cases where the Birmingham burner had been adopted they would, no doubt, have to contend with the difficulty of getting bad results. The burner placed upon the meter was an ordinary consumer's burner, and not specially made for the purposes of the photometer. Mr. Vernon Harcourt thought there would be a difficulty in reading the exact height by inches, because of inequalities in the height of the flame. Supposing a burner were made expressly for photometric purposes, no doubt the flame could be kept perfectly level on the top, but the slight variations in that standard burner did not make any appreciable difference. Several members of the Institution had tried the regulation of the flame themselves, and the only difference was about half a candle, not a great difference when it was remembered that they had never seen the instrument before. Mr. Vernon Harcourt had also spoken of the more easy method of reading the height with the jet-photometer. This instrument showed the illuminating power of the gas in a manner somewhat similar to the Illuminating Power Meter, namely, by the height of the flame. If the gas was rich, the flame went up higher; and if poor, the flame was low. By regulating always to one height of flame, and reading off the pressure required to give that height of flame, a correct estimate could be formed of the illuminating power of the gas. There was only one difficulty, which he hoped to remove, and that was the difficulty of the Standard Burner. For every quality of gas at the present moment a different standard burner was required; and as they all differed among themselves, it was difficult to fix the readings of the jet-photometer to any particular point which would be universally correct; for if it was correct for one standard burner, it was sure to be wrong for another. That difficulty was again complicated, because with gas beyond twenty candles the Argand burner was replaced by a burner which gave a flat flame, and the flat-flamed burner gave a higher result for the higher illuminating power of the gases than it ought to. Up to 30-candle gas it made a difference of about three candles. That difficulty did not exist with the Illuminating Power Meter, because it was adapted for gas from twelve candles to thirty-two candles; and although with 35-candle gas there seemed to be a little difference, it depended upon the chimney placed over the flame. If a long chimney was put on, which favoured the richer gas and deteriorated the poorer, it would give the benefit to the richer gas; but by putting a chimney suitable to both kinds, the illuminating power of the burner could be made exactly the same, whether 12- or 35-candle gas. Dr. Pole mentioned that, ac-

Digitized by Google

cording to law, official testing must be made with 5 cubic feet of gas; but it was known that for a long time that had not been complied with. In the case of Birmingham, in particular, if the gas was over fourteen candles, it used to flare over the chimney, and it therefore became necessary to reduce the quantity; and so also in many other places. In London it was not so done, because the Gas Referees had made a provision to avoid it. They said that when the gas was so rich that it tailed over the top of the chimney, a still longer chimney should be put on. If that was done in London, it was just as easy to do it in other places, as Birmingham, where the burners would not consume the proper quantity of gas. His proposition was to provide one standard burner for all qualities of gas, by which means all difficulty was avoided, simply by reducing the quantity of gas used in accordance with its richness; and so correctly and proportionately to estimate the quality of the gas burned. With respect to the radiometer, there appeared to be some difficulty in its application to gas photometrical purposes. It certainly went round fastest with the hottest burner; and it would go round as fast with a heated poker as it would with the burner. No doubt the movement was as much affected by heat as by light; but with one standard burner and one height of flame, if the radiometer was placed at a sufficient distance, that difficulty might be got over to a great extent. Also if the number of revolutions could be reduced, it might be possible to check the accuracy of the burner, and so have another check upon the sperm candle, or perhaps eventually do without sperm candles at all.

Digitized by Google

February 22, 1876.

GEORGE ROBERT STEPHENSON, President, in the Chair.

No. 1,457.—"On the Probable Errors of Levelling; with Rules for the Treatment of Accumulated Errors." By WILFRID AIRY, B.A., M. Inst. C.E.

As the members of the Institution are no doubt familiar with the processes of levelling, it is not intended to do more than glance at the various precautions taken to provide against accidental errors. In most engineering works it is unnecessary to give much attention to the small discrepancies between the results arrived at by different observers; but in the case of a complicated system of long lines of levelling, such as is required for the levels of an entire country, the aggregation of small errors becomes formidable, and the proper treatment of them requires considerable method and skill. In the present Paper the Author has dealt with errors of levelling under the following heads:—

A. The different classes of errors which occur in all levelling operations.
B. The probable errors of levelling on ground of different degrees of inclination, as deduced from standard levelling in different countries.
C. The treatment of probable errors in the case of a complex system of levelled lines.
D. Remarks on the instruments and methods of working used in accurate levelling.

A. THE DIFFERENT CLASSES OF ERRORS WHICH OCCUR IN ALL LEVELLING OPERATIONS.

These are of three kinds, viz.:—
(1) Mistakes.
(2) Instrumental errors.
(3) Errors of observation.

The first two of these are not of the nature of graduated errors. 'Mistakes' arise from want of care in reading the staff, or the bubble, or in booking the readings: as well as from the foot of the staff

Digitized by Google

being shifted between the readings, and from want of care in holding the staff vertical. The only effectual safeguard is to check the work throughout by independent observers, and to divide the distance into short sections defined by benchmarks. As a check on individual levelling, it has been customary in Great Britain and in India to graduate the staves differently on the two sides, and always to read both sides of the staff: the readings of the two sides ought, of course, to differ always by a constant quantity. To secure the foot of the staff from being shifted between the readings, it is usual to place the staff either upon a peg driven into the ground, or upon a three-cornered iron shoe jammed down firmly on the ground. To insure, as far as possible, the verticality of the staves, it is usual to have small levels, or plummets, let into them at one side, and in India the staves were guyed upright by ropes.

(2) Instrumental errors are either errors of collimation, of level, or of form of the telescope, the last-mentioned only coming into question when the spirit-level is not permanently attached. None of these will affect the accuracy of the levelling, so long as the instrument is always placed exactly midway between the staves: this condition is essential to all exact levelling, and has been observed in all operations of a standard character. Along with instrumental errors must be classed those of length and graduation of the staves: in general the graduation of the staves is very uniform, but errors of absolute length are not uncommon, and in all exact operations a standard bar should be kept at hand for testing the length of the staves.

(3) Errors of observation are the small graduated errors inseparable from all operations which depend upon human nerves and judgment. For any single operation they are very small; but, as they are repeated with every operation, they may amount to a considerable aggregate at the termination of a long course of work. For different persons the errors will, in all probability, have different values, as they depend upon natural and acquired keenness of estimation. They are, in fact, due to the degree of uncertainty existing in the mind of the observer as to the exact value of the several quantities which he has to estimate, and it is to be presumed that his estimate of these quantities is as likely to exceed as to fall short of the true value. Errors of judgment (but not 'mistakes') also occur in reading the staves, and the bubble; and errors also arise from small oscillations of the staves from the vertical, but not from carelessness or any determined bias on the part of the staff-holder. To these must be

Digitized by Google

added slight alterations in length of the staves caused by changes of temperature or moisture: which, though sensible in amount, were found in the Swiss levelling to be very slow, small, and irregular, so that no law could be safely deduced. The combination of these produces the final error, and it is with these that the present Paper is chiefly intended to deal. There is no safeguard against errors of observation, but their amount may be reduced by the selection of observers of natural quickness of sight and decision, well trained to the work.

Dr. Whewell and Colonel Walker have noticed that, in general, the results of levelling any given line differ considerably according as the line is levelled in one direction or the other. Colonel Walker attributes this mainly to the dislevelling effect of the sun's heat upon the instruments, and to errors of reading the bubble caused by the oblique direction in which the light falls upon it. To obtain reliable results it is essential that every line should be levelled both ways, and the mean of the results adopted as the true value, as the various circumstances of heat, light, ground, weather, and indeed everything that would tend to give a bias to the levelling, would stand a chance of being reversed or modified.

B. The Probable Errors of Levelling on Ground of different Degrees of Inclination, as deduced from Standard Levelling in different Countries.

In general the results obtained by different observers on a long line of levelling are different. But there are not unfrequently cases, even on very long lines and on steep ground, in which the results of the different observers agree closely, and it is usual to quote such close agreement as a proof of the accuracy of the common result. Nevertheless it is always highly probable that the result arrived at is incorrect: for no observer could reckon on arriving at the same result each time, if he re-levelled the section several times over, and yet he would probably be unable to say that one result was more correct than another. Therefore the chances are greatly against the probability of the common result being correct, and it may be assumed that the result is in error, but that the errors of the different observers have all run in the same direction, and are of equal amount.

Since then it would be quite unsafe to form conclusions as to the probable error of the levelling on any line from the actual discordance of the observations on that particular line, and since it is

Digitized by Google

necessary to be furnished with values of the probable errors in order to combine the results on different lines in the most probable manner, it becomes necessary to form rules or tables for arriving at the probable errors either by calculation or inspection. This subject has received much consideration from Messrs. Hirsch and Plantamour at pages 108–121 of the "Nivellement de la Suisse."

Obviously the amount of the error on any given line will in general depend upon the length of the line and the steepness of the ground. If length of line only were considered as affecting the error, and (e) be taken to represent the amount of the error which may be admitted as fairly due to a single mile of the levelling, then the probable error on a line of length (k) miles will be $e\sqrt{k}$. (See Airy's "Theory of Errors of Observation," art. 53.) But when there is much difference in the nature of the ground, it is certain that the error for any line will greatly depend upon the sum of the ups and downs on that line. Errors in the lengths of the staves and in small oscillations of the staves will certainly be proportional to the sum of the ups and downs: also, in all probability, steep ground will lead to high elevations where the effect of the wind and rain will be more severely felt, and the uncertainty of the readings will in consequence be greater. If the sum of the ups and downs only were considered as affecting the error, and (f) be taken to represent the amount of the error which may be admitted as due to a rise or fall of 1 foot, then the probable error on any line will be (f) times the sum of the ups and downs on that line.

In the application of these formulæ to the case of a 'polygon,' Messrs. Hirsch and Plantamour have apparently made no attempt to combine their effects. They have deduced the values of (e) and (f) from the closing error of the polygon, by assuming that the closing error is uniformly distributed over the entire length of the polygon, and have applied either one or other of the formulæ to determine the corrections to the several sides of the polygon, as a first approximation. Then if, as was usually the case, some of the sides of the polygon went to form adjacent polygons, new values were ascertained for the corrections to those common sides from similar operations with the adjacent polygons. These new values were then imported into the original polygon, and a new closing error obtained for that polygon, from which in the same way as before second approximations to the values for the several sides were established. And a similar method was pursued for third and fourth approximations.

Digitized by Google

This plan appears open to several objections. First, it is certain that the error due to any given line depends both upon the length of the line and the contour of the ground, and whatever formula is used for the corrections should have regard to both. Secondly, it is very unsafe to use the actual closing error of a polygon as the basis of the corrections which are to be applied to the several sides: for it might well happen that the closing error was exceedingly small, while the error at intermediate points was large. Thirdly, the method of successive approximations, as described, is laborious and unsatisfactory. As soon as any network of lines has been completely levelled, no matter how complicated it may be, there is no difficulty in applying the Theory of Probable Errors so as to obtain directly and simultaneously the most probable values for the levels of all the points of the system.

In considering the question of dealing, in a satisfactory way, with the adjustment of the levels on a complicated system, it occurred to the Author to frame Tables of Probable Errors, such as would be applicable to the circumstances of the different lines of the system. The data for framing such tables would be drawn from the official records of standard levelling in different countries, and the value of the tables when framed would depend in a great degree upon the mass of statistics reduced in order to compile them. Through the courtesy of Colonel Clarke, R.E., of the Ordnance Survey Department, and of Colonel Walker, of the Survey Department of India, the Author has obtained access to the original records of the check levelling executed on long lines in Great Britain and in India, and he has extracted similar information with reference to the Swiss levelling from the "Nivellement de la Suisse."

A critical examination of the discrepancies between observers on the same lines of levels, showed that the average amount of the discrepancies depended very much upon the inclination of the ground. If the average inclination between two benchmarks was steep, no matter whether parts of the distance were uphill and other parts downhill, then the discrepancy was greater for that section than for another section on which the ground was flatter, and this rule was found to hold with great regularity. It was therefore possible to frame a Table of Errors suitable to different inclinations of ground, and the application of the table is as follows:—Suppose that a line of (r) miles in length has been levelled, and that the character of the ground corresponds with one or other of the classes mentioned in the Table. The probable error due to a single mile of levelling on such ground would be taken

Digitized by Google

from the Table by simple inspection, and this probable error multiplied by $\sqrt{r}$ would give the probable error due to the whole line. By this method due account would be taken of all the principal causes of error, as depending upon the contour of the ground and the length of the line, and the probable error for each line of the system would be determined on a broad and uniform basis.

The results of the reduction of a large mass of observations in Great Britain, India, and Switzerland are given in Table I. There appeared to be no practical advantage in quoting the average differences for very small changes of inclination of the ground, and the differences are therefore given for the gradients included between broad and well-defined limits of inclination. Whenever the differences were tested for gradients not quoted, the law of increase of differences with increase of inclination was observed to hold good with considerable uniformity. Thus, for instance, in the English levelling the average differences in a single mile were—

	Foot.
For gradients below 1 in 100	0·024
Do. between 1 in 100 and 1 in 50	0·035
Do. do. 1 in 50 and 1 in 20	0·042

TABLE I.—AVERAGE DIFFERENCES in a SINGLE MILE of the RESULTS OBTAINED by TWO OBSERVERS on GROUND of DIFFERENT DEGREES of INCLINATION in GREAT BRITAIN, INDIA, and SWITZERLAND.[1]

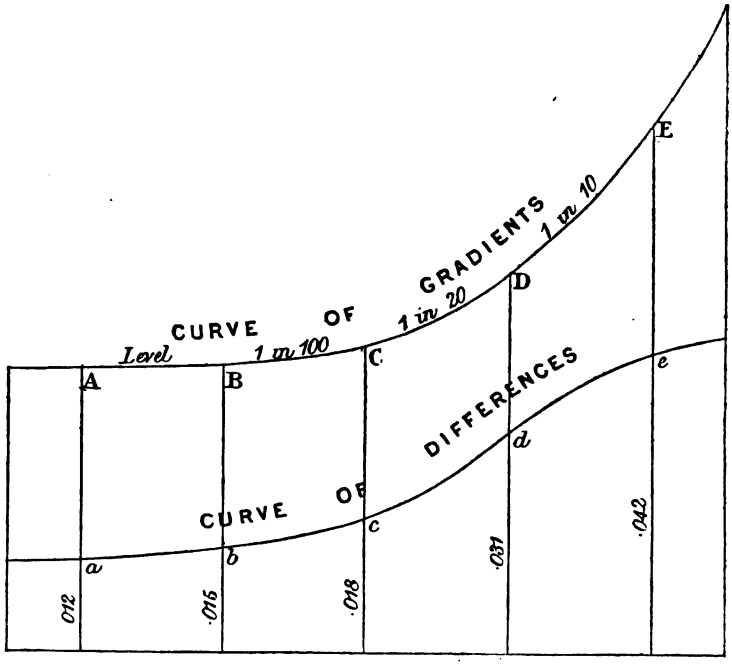
——	Great Britain.	India.	Switzerland.
	Foot.	Foot.	Foot.
(1) Average difference in a single mile on ground nearly level, and in very favourable circumstances of weather . . .	**·0230**	**·0142**	·0125
(2) Average difference in a single mile on ground of a slightly undulating character, where the gradients do not exceed 1 in 100	·0238	·0168	·0148
(3) Average difference in a single mile on ground where the gradients lie entirely between 1 in 100 and 1 in 20	·0379	**·0208**	·0183
(4) Average difference in a single mile on ground where the gradients lie entirely between 1 in 20 and 1 in 10	**·0566**	**·0350**	·0308
(5) Average difference in a single mile on steep and rough ground where the gradients are frequently steeper than 1 in 10 . .	..	..	·0416

[1] The quantities marked in black figures are estimated from the analogy afforded by the Swiss Levelling, as no direct data could be furnished.

Digitized by Google

To exhibit more clearly the nature of the law which regulates the magnitude of errors in levelling, the Author has prepared a diagram (Fig. 1), in which the successive changes of gradient from 'level' to upwards of 1 in 10 are represented by a curve of gradients, and the corresponding magnitudes of 'differences' by a curve plotted from the observed results of the Swiss Levelling. Such a diagram may be usefully applied to obtain the probable difference of results on ground of variable character. Thus, for

FIG. 1.



instance, if the gradients on a given line range from 1 in 100 to 1 in 10 (represented by the portion B C D E of the upper curve) in about equal proportions, the probable difference of results might be taken pretty correctly by inspection from the corresponding portion, *b c d e*, of the lower curve. But the inspection method will not be quite accurate, and it may be convenient to form accurately a table which would be applicable to most circumstances of levelling.

Digitized by Google

TABLE II.—AVERAGE DIFFERENCES in a SINGLE MILE DUE to GROUND of VARIABLE INCLINATION—COMPUTED from the RESULTS of TABLE A. by the FORMULA

Prob. Diff. = $\sqrt{\text{Mean of squares of diffs. due to the several slopes of ground.}}$

Character of the Ground.	Average Difference in a single Mile.		
	Great Britain.	India.	Switzerland.
	Foot.	Foot.	Foot.
(1) "Level ground" in very favourable circumstances of weather. Example.—A broad level valley or margin of a lake	·0230	·0142	·0125
(2) "Gently undulating ground," where the gradients rarely, if at all, exceed 1 in 100. Example.—Most of the roads in India . .	·0238	·0168	·0148
(3) "Steeply undulating ground," where the gradients rarely, if at all, exceed 1 in 20. Example.—Most of the roads in Great Britain	·0316	·0189	·0166
(4) "Mountain roads," where the gradients rarely, if at all, exceed 1 in 10. Example.—The mountain roads in Switzerland	·0416	·0254	·0224
(5) "Very steep and rough ground," where the gradients frequently exceed 1 in 10, and the levelling is carried over mere road tracks or paths	..	..	·0416

NOTE.—Quantities in black partly estimated as per Table I.

Having thus determined the 'average differences' from the results of standard levelling in different countries, it remains to form a table of the probable errors due to those differences. The proper method of doin g this will be found in the "Theory of Errors of Observation," art. 60; and from the formulæ of that article it can be shown that if there be two independent measures of the same quantity the probable error of each measure is 0·477 × difference of the measures, and the probable error of the mean of the two measures is 0·337 × difference of the measures. With these co-efficients it is easy to frame a table of probable errors applicable to the cases of lines which have been levelled once or twice.

Digitized by Google

TABLE III.—PROBABLE ERRORS of the RESULTS of SINGLE or DUPLICATE LEVELLING on GROUND of DIFFERENT CHARACTERS, FORMED from the RESULTS of the SWISS LEVELLING.

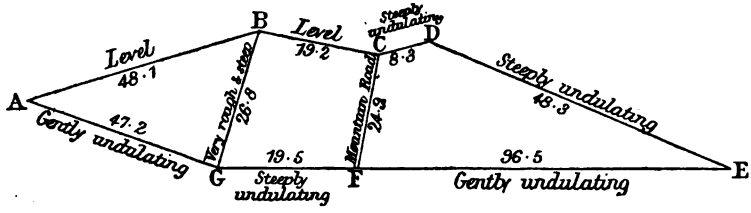
Character of the Ground. (For Definitions, see Table II.)	Average Difference in a single Mile of Two Observers (see Table B).	Probable Error in a single Mile of each Observer. Multiplier = ·477.	Probable Error in a single Mile of the Mean of Two Observers. Multiplier = ·337.
	Foot.	Foot.	Foot.
Level ground	·0125	·00596	·00421
Gently undulating ground . . .	·0148	·00706	·00499
Steeply undulating ground . . .	·0166	·00792	·00559
Mountain roads	·0224	·01068	·00755
Very steep and rough ground . .	·0416	·01984	·01402

C. THE TREATMENT OF PROBABLE ERRORS IN THE CASE OF A COMPLEX SYSTEM OF LEVELLED LINES.

This is illustrated by working out in detail an example showing the application of the theory of probable errors in adjusting the levels of a number of points connected by lines of levelling on the 'polygon' system, the closing error of the chief polygon being 0·286 foot.

Let A B C D E F G A be the polygon system (Fig. 2), of which all the lines have been separately levelled.[1] The lines B C, C D, C F, and F G have been levelled twice each, and the remaining lines once. The length in miles, and the character of the ground, are written against each line.

FIG. 2.



The first thing to be done is to form a table of the probable errors of the several lines from Table III. If a line has been levelled once only, the 'probable error in a single mile' is to be taken from the third column of Table III.; but if twice, it is to be taken from the fourth column of the table, and applied to the mean of the observed results.

[1] The polygon system of the example, with the lengths of the lines and the observed levels of the several points, is taken from an actual case in the "Nivellement de la Suisse." The description of the ground is not given in the "Nivellement," and is to some extent hypothetical.

Digitized by Google

TABLE IV.—PROBABLE ERRORS of the LINES A B, B C, C D, &c.

Section.	Observed Difference of Level of the two ends of the Section.	Character of the Ground.	Number of Times Levelled.	Length of Section.	Probable Error in a single Mile, from Table C.	Probable Error of the Section = Probable Error in a single Mile × √Length in Miles.
	Feet.			Miles.	Foot.	Foot.
A B	193·458	Level . .	Once .	48·1	·00596	·041
B C	15·860[1]	Level . .	Twice	19·2	·00421	·018
C D	699·887[1]	Steeply undulating .	Twice	8·3	·00559	·016
D E	−1322·470	Steeply undulating .	Once .	48·3	·00792	·055
E F	955·880	Gently undulating .	Once .	96·5	·00706	·069
F G	155·125[1]	Steeply undulating .	Twice	19·5	·00559	·025
G A	−697·454	Gently undulating .	Once .	47·2	·00706	·048
B G	503·961	Very rough and steep	Once .	26·8	·01984	·103
C F	332·935[1]	Mountain road . .	Twice	24·9	·00755	·038

↑ Closing Error = ·286 ↓

With these probable errors the equations for the determination of the levels of the points A, B, C, D, &c., can be formed, in the most probable manner, in accordance with the method of 'least squares.'[2] The details of the work are given in the Appendix (p. 187). The final results, together with the effect of the corrections, are shown in Table V. The heights are measured from a datum-level 500 feet below the point A.

TABLE V.—FINAL RESULTS and EFFECT of the CORRECTIONS.

	Height above Datum.		Difference.
	As obtained by levelling round from A through B, C, D, &c., to A.	As corrected by Theory.	
	Feet.	Feet.	Foot.
Level of point A	500·000	500·000	·000
Do. do. B	693·458	693·464	+ ·006
Do. do. C	709·318	709·325	+ ·007
Do. do. D	1,409·205	1,409·202	− ·003
Do. do. E	86·735	86·618	− ·117
Do. do. F	1,042·615	1,042·319	− ·296
Do. do. G	1,197·740	1,197·445	− ·295
Do. do. A′	500·286	500·000	− ·286

[1] Mean results.

[2] *Vide* "Theory of Errors of Observation," art. 95.

Digitized by Google

Thus the effect of the corrections is to raise the points B and C a little, and to lower E, F, G, and A′ considerably. This seems consistent with the nature of the ground, which from A to D is favourable, and the corrections are small. From D through E and F to G the distance is long and the ground rather steep, and it is accordingly on these lengths that the corrections are heavy. At the same time the cross lines B G and C F, though short, are steep, and would well allow of the heavy corrections required by the corrected levels of G and F. The final correction to A′ is of course the closing error of the polygon, as shown by the observed levels.

D. Remarks on the Instruments and Methods of Working used in Accurate Levelling.

For the standard levelling in Great Britain, India, and Switzerland, Y levels were used. This construction offers facilities for the quick and accurate determination of the collimation error and the level error. Its chief disadvantage is that, from want of rigidity in the mounting, it sometimes happens that the internal tube (which carries the object glass) does not slide truly in the external tube, so that the optical axis does not keep constant in position when focussing the telescope. This defect is remedied in part by Mr. Gravatt's construction, which, however, introduces inconvenience in respect of the collimation adjustment. In the instruments used for the Swiss levelling the spirit-level is movable, and is clipped upon the telescope tube—a construction which has no apparent advantage. In the English and in the Indian instruments the spirit-level is always attached to the telescope. In some levels recently constructed for foreign governments by Messrs. Troughton and Simms, the spirit-level is attached to the frame which carries the telescope, instead of to the telescope itself; by this arrangement the level is more firmly secured and less liable to accident.

Table VI. contains the essential information relating to the instruments and staves used in the initial levelling of different countries.

In the Swiss levelling the distances were always measured by taking the reading on the staff of two fixed wires in the diaphragm of the telescope, and corrections were afterwards applied with much labour in respect of all the instrumental errors due to the difference of distances. In Great Britain and in India the distances were always chained equal.

Digitized by Google

TABLE VI.—INSTRUMENTS and STAVES used in INITIAL LEVELLING.[1]

		Great Britain.	India.	Switzerland.	France.
Spirit-level	Seconds of arc in tilt of telescope corresponding to $\frac{1}{10}$th of an inch run of the bubble	5″	3½″	3″	3″ to 7″
Telescope	Focal length	24 ins.	21 ins.	16 ins.	19 ins.
	Diameter of object glass	2½ ,,	2 ,,	1¼ ,,	1½ ,,
	Magnifying power	50	42	42	36
Staves	Length	10 ft.	16 ft.	9·84 ft.	..
	Graduated to	$\frac{1}{100}$,,	$\frac{1}{100}$,,	$\frac{3}{100}$,,	$\frac{6}{100}$ ft.
	Read to	$\frac{1}{1000}$,,	$\frac{1}{1000}$,,	$\frac{3}{1000}$,,	$\frac{3}{1000}$,,
Maximum distance of staves from instrument		5 chs.	10 chs.	5 chs.	6½ chs.

In India Colonel Walker discovered that the instruments had a tendency to settle on their axis between the reading of the back and forward staves. This would tend to produce a cumulative error, and he has therefore established the rule of alternating the order of observation at successive stations of the instrument, by reading the back staff first at one station and the forward staff first at the next. The special necessity for this appears to be mainly due to the practice of unshipping the instruments at every station for removal to the next station. To counteract the cumulative error originally noticed by Dr. Whewell, which is introduced by levelling a line continuously in the same direction, all the lines of the initial levelling in Great Britain were levelled both ways from end to end. In India the same end is gained by splitting up the long lines into short sections of 4 or 5 miles in length, and levelling alternate sections in opposite directions. But no precautions appear to have been taken in the Swiss and French levelling to guard against these accumulated errors.

Errors may easily be caused by an inaccurate method of placing benchmarks. Thus it has been usual in England to cut benchmarks deeply on the vertical faces of walls, and from the inconvenience of ascertaining the exact level of the centre of the mark, it is easy to make at once an error as large as would be generated

[1] The metrical values of the foreign measures have been reduced to English units for the sake of comparison.

Digitized by Google

in a considerable length of levelling. In the Swiss levelling the benchmarks were always defined by bronze bolts let into a horizontal face.

By due attention to all the ascertained causes of error a high degree of accuracy may be secured, and this Paper cannot better close than with a reference to the astonishing results obtained in India under the able management of Colonel Walker. From the Report on the Spirit Levelling Operations in India dated 1866 the following information is extracted:—

Section.	Length.	Maximum Divergence of two Observers.	Terminal Divergence.
	Miles.	Foot.	Foot.
Calcutta to Tilliagarhí	242	·20	·15
Tilliagarhí to Patka Gerouli. . .	346	·40	·38
Agra to Patka Gerouli	342½	·15	·06

APPENDIX.

Digitized by Google

APPENDIX.

DETAILS of WORKING-OUT of the EXAMPLE on page 182 by the METHOD of 'LEAST SQUARES.'

Let a, b, c, d, &c., be the corrected levels of the points A, B, C, D, &c. Then since the differences of level of the successive points have been determined approximately, as given below, the following equations are obtained:—

	Feet.		Foot.
$b - a =$	193·458	with probable error =	·041
$c - b =$	15·860[1]	" " =	·018
$d - c =$	699·887[1]	" " =	·016
$e - d =$	− 1322·470	" " =	·055
$f - e =$	955·880	" " =	·069
$g - f =$	155·125[1]	" " =	·025
$a - g =$	− 697·454	" " =	·048
$g - b =$	503·961	" " =	·103
$f - c =$	332·935[1]	" " =	·038

From the foregoing equations it follows that—

$$\frac{b}{\cdot 041} - \frac{a}{\cdot 041} = \frac{193\cdot 458}{\cdot 041} \text{ with probable error} = 1$$

$$\frac{c}{\cdot 018} - \frac{b}{\cdot 018} = \frac{15\cdot 860}{\cdot 018} \text{ " " } = 1$$

$$\frac{d}{\cdot 016} - \frac{c}{\cdot 016} = \frac{699\cdot 887}{\cdot 016} \text{ " " } = 1$$

$$\frac{e}{\cdot 055} - \frac{d}{\cdot 055} = -\frac{1322\cdot 470}{\cdot 055} \text{ " " } = 1$$

$$\frac{f}{\cdot 069} - \frac{e}{\cdot 069} = \frac{955\cdot 880}{\cdot 069} \text{ " " } = 1$$

$$\frac{g}{\cdot 025} - \frac{f}{\cdot 025} = \frac{155\cdot 125}{\cdot 025} \text{ " " } = 1$$

$$\frac{a}{\cdot 048} - \frac{g}{\cdot 048} = -\frac{697\cdot 454}{\cdot 048} \text{ " " } = 1$$

$$\frac{g}{\cdot 103} - \frac{b}{\cdot 103} = \frac{503\cdot 961}{\cdot 103} \text{ " " } = 1$$

$$\frac{f}{\cdot 038} - \frac{c}{\cdot 038} = \frac{332\cdot 935}{\cdot 038} \text{ " " } = 1$$

From these equations are formed the seven equations which will give the most

[1] Quantities marked thus are the mean results of the duplicate levelling on those lines.

Digitized by Google

probable values of a, b, c, &c., according to the method of least squares, as follow :—

For a—

$$+\frac{a}{(\cdot041)^2}-\frac{b}{(\cdot041)^2}=-\frac{193\cdot458}{(\cdot041)^2}$$
$$+\frac{a}{(\cdot048)^2}-\frac{g}{(\cdot048)^2}=-\frac{697\cdot454}{(\cdot048)^2}$$

$$a\left\{\frac{1}{(\cdot041)^2}+\frac{1}{(\cdot048)^2}\right\}-\frac{b}{(\cdot041)^2}-\frac{g}{(\cdot048)^2}=-\frac{193\cdot458}{(\cdot041)^2}-\frac{697\cdot454}{(\cdot048)^2}$$

$$a\times 1028\cdot9117-b\times 594\cdot8838-g\times 434\cdot0279=-417,799\cdot5$$

For b—

$$+\frac{b}{(\cdot041)^2}-\frac{a}{(\cdot041)^2}=\frac{193\cdot458}{(\cdot041)^2}$$
$$+\frac{b}{(\cdot018)^2}-\frac{c}{(\cdot018)^2}=-\frac{15\cdot860}{(\cdot018)^2}$$
$$+\frac{b}{(\cdot103)^2}-\frac{g}{(\cdot103)^2}=-\frac{503\cdot961}{(\cdot103)^2}$$

$$b\left\{\frac{1}{(\cdot041)^2}+\frac{1}{(\cdot018)^2}+\frac{1}{(\cdot103)^2}\right\}-\frac{a}{(\cdot041)^2}-\frac{c}{(\cdot018)^2}-\frac{g}{(\cdot103)^2}$$
$$=\frac{193\cdot458}{(\cdot041)^2}-\frac{15\cdot860}{(\cdot018)^2}-\frac{503\cdot961}{(\cdot103)^2}$$

$$b\times 3775\cdot5634-a\times 594\cdot8838-c\times 3086\cdot420-g\times 94\cdot2596=18,631\cdot20$$

For c—

$$+\frac{c}{(\cdot018)^2}-\frac{b}{(\cdot018)^2}=\frac{15\cdot860}{(\cdot018)^2}$$
$$+\frac{c}{(\cdot016)^2}-\frac{d}{(\cdot016)^2}=-\frac{699\cdot887}{(\cdot016)^2}$$
$$+\frac{c}{(\cdot038)^2}-\frac{f}{(\cdot038)^2}=-\frac{332\cdot935}{(\cdot038)^2}$$

$$c\left\{\frac{1}{(\cdot018)^2}+\frac{1}{(\cdot016)^2}+\frac{1}{(\cdot038)^2}\right\}-\frac{b}{(\cdot018)^2}-\frac{d}{(\cdot016)^2}-\frac{f}{(\cdot038)^2}$$
$$=\frac{15\cdot860}{(\cdot018)^2}-\frac{699\cdot887}{(\cdot016)^2}-\frac{332\cdot935}{(\cdot038)^2}$$

$$c\times 7685\cdot1908-b\times 3086\cdot420-d\times 3906\cdot250-f\times 692\cdot5208$$
$$=-2,915,546\cdot78$$

For d—

$$+\frac{d}{(\cdot016)^2}-\frac{c}{(\cdot016)^2}=\frac{699\cdot887}{(\cdot016)^2}$$
$$+\frac{d}{(\cdot055)^2}-(\cdot055)^e=\frac{1322\cdot470}{(\cdot055)^2}$$

Digitized by Google

$$d\left\{\frac{1}{(\cdot016)^2}+\frac{1}{(\cdot055)^2}\right\}-\frac{c}{(\cdot016)^2}-\frac{e}{(\cdot055)^2}=\frac{699\cdot887}{(\cdot016)^2}+\frac{1322\cdot470}{(\cdot055)^2}$$

$$d\times 4236\cdot8285-c\times 3906\cdot250-e\times 330\cdot5785=3,171,113\cdot1$$

For e—

$$+\frac{e}{(\cdot055)^2}-\frac{d}{(\cdot055)^2}=-\frac{1,322\cdot470}{(\cdot055)^2}$$

$$+\frac{e}{(\cdot069)^2}-\frac{f}{(\cdot069)^2}=-\frac{955\cdot880}{(\cdot069)^2}$$

$$e\left\{\frac{1}{(\cdot055)^2}+\frac{1}{(\cdot069)^2}\right\}-\frac{d}{(\cdot055)^2}-\frac{f}{(\cdot069)^2}=-\frac{1322\cdot470}{(\cdot055)^2}-\frac{955\cdot880}{(\cdot069)^2}$$

$$e\times 540\cdot6184-d\times 330\cdot5785-f\times 210\cdot0399=-637,953\cdot1$$

For f—

$$+\frac{f}{(\cdot069)^2}-\frac{e}{(\cdot069)^2}=\frac{955\cdot880}{(\cdot069)^2}$$

$$+\frac{f}{(\cdot025)^2}-\frac{g}{(\cdot025)^2}=-\frac{155\cdot125}{(\cdot025)^2}$$

$$+\frac{f}{(\cdot038)^2}-\frac{c}{(\cdot038)^2}=\frac{332\cdot935}{(\cdot038)^2}$$

$$f\left\{\frac{1}{(\cdot069)^2}+\frac{1}{(\cdot025)^2}+\frac{1}{(\cdot038)^2}\right\}-\frac{e}{(\cdot069)^2}-\frac{g}{(\cdot025)^2}-\frac{c}{(\cdot038)^2}$$
$$=\frac{955\cdot880}{(\cdot069)^2}-\frac{155\cdot125}{(\cdot025)^2}+\frac{332\cdot935}{(\cdot038)^2}$$

$$f\times 2502\cdot5607-e\times 210\cdot0399-g\times 1600\cdot0-c\times 692\cdot5208=183,137\cdot4$$

For g—

$$+\frac{g}{(\cdot025)^2}-\frac{f}{(\cdot025)^2}=\frac{155\cdot125}{(\cdot025)^2}$$

$$+\frac{g}{(\cdot048)^2}-\frac{a}{(\cdot048)^2}=\frac{697\cdot454}{(\cdot048)^2}$$

$$+\frac{g}{(\cdot103)^2}-\frac{b}{(\cdot103)^2}=\frac{503\cdot961}{(\cdot103)^2}$$

$$g\left\{\frac{1}{(\cdot025)^2}+\frac{1}{(\cdot048)^2}+\frac{1}{(\cdot103)^2}\right\}-\frac{f}{(\cdot025)^2}-\frac{a}{(\cdot048)^2}-\frac{b}{(\cdot103)^2}$$
$$=\frac{155\cdot125}{(\cdot048)^2}+\frac{697\cdot454}{(\cdot048)^2}+\frac{503\cdot961}{(\cdot103)^2}$$

$$g\times 2128\cdot2875-f\times 1600\cdot0-a\times 434\cdot0279-b\times 94\cdot2596=598,417\cdot68$$

Digitized by Google

Collecting the equations we have for the determination of a, b, c, d, e, f, g:—

$$
\begin{aligned}
&(1)\ a \times 1028{\cdot}9117 - b \times 594{\cdot}8838 - g \times 434{\cdot}0279 = -417{,}799{\cdot}5\\
&(2)\ b \times 3775{\cdot}5634 - a \times 594{\cdot}8838 - c \times 3086{\cdot}420 - g \times 94{\cdot}2596 = 18{,}631{\cdot}20\\
&(3)\ c \times 7685{\cdot}1908 - b \times 3086{\cdot}420 - d \times 3906{\cdot}250 - f \times 692{\cdot}5208 = -2{,}915{,}546{\cdot}78\\
&(4)\ d \times 4236{\cdot}8285 - c \times 3906{\cdot}250 - e \times 330{\cdot}5785 = 3{,}171{,}113{\cdot}1\\
&(5)\ e \times 540{\cdot}6184 - d \times 330{\cdot}5785 - f \times 210{\cdot}0399 = -637{,}953{\cdot}1\\
&(6)\ f \times 2502{\cdot}5607 - e \times 210{\cdot}0399 - g \times 1600{\cdot}00 - c \times 692{\cdot}5208 = 183{,}137{\cdot}4\\
&(7)\ g \times 2128{\cdot}2875 - f \times 1600{\cdot}000 - a \times 434{\cdot}0279 - b \times 94{\cdot}2596 = 598{,}417{\cdot}68
\end{aligned}
$$

Since, however, it is seen that the last equation would result from the addition of the first six equations, it is not an independent equation, and must be excluded. There are then six equations among seven unknown quantities, and the values of a, b, c, &c., are indeterminate; this ought evidently to be the case, since in the formation of the equations no account was taken of absolute levels, but only of differences of level. Adopting, however, the level of the point A as the datum-level, and putting $a = 0$. Then the other six quantities, b, c, d, e, f, g, may be determined as follows:—

From (1)
$$g = \frac{417{,}799{\cdot}5}{434{\cdot}0279} - b \times \frac{594{\cdot}8838}{434{\cdot}0279};$$

$$\therefore g \times 94{\cdot}2596 = 90{,}735{\cdot}22 - b \times 129{\cdot}1934$$
$$g \times 1600{\cdot}00 = 1{,}540{,}176{\cdot}0 - b \times 2192{\cdot}980$$

Therefore equations 2, 3, 4, 5, 6, become

$$
\begin{aligned}
&(\alpha)\ b \times 3904{\cdot}7568 - c \times 3086{\cdot}420 = 109{,}366{\cdot}42\\
&(\beta)\ c \times 7685{\cdot}1908 - b \times 3086{\cdot}420 - d \times 3906{\cdot}250 - f \times 692{\cdot}5208 = -2{,}915{,}546{\cdot}78\\
&(\gamma)\ d \times 4236{\cdot}8285 - c \times 3906{\cdot}250 - e \times 330{\cdot}5785 = 3{,}171{,}113{\cdot}1\\
&(\delta)\ e \times 540{\cdot}6184 - d \times 330{\cdot}5785 - f \times 210{\cdot}0399 = -637{,}953{\cdot}1\\
&(\epsilon)\ f \times 2502{\cdot}5607 - e \times 210{\cdot}0399 + b \times 2192{\cdot}980 - c \times 692{\cdot}5208 = 1{,}723{,}313{\cdot}4
\end{aligned}
$$

From (α)
$$c = -\frac{109{,}366{\cdot}42}{3086{\cdot}420} + b \times \frac{3904{\cdot}7568}{3086{\cdot}420}.$$

$$\therefore c \times 7685{\cdot}1908 = -272{,}322{\cdot}6 + b \times 9722{\cdot}852$$
$$\text{and } c \times 3906{\cdot}250 = -138{,}416{\cdot}8 + b \times 4941{\cdot}958$$

Also it is noticed that by adding together all the equations $\alpha, \beta, \gamma, \delta, \epsilon$, the co-efficients of c, d and e vanish, and the resulting equation is as follows:—

$$b \times 3011{\cdot}3168 + f \times 1600{\cdot}00 = 1{,}450{,}293{\cdot}04$$

This gives
$$f = \frac{1{,}450{,}293{\cdot}04}{1600} - b \times \frac{3{,}011{\cdot}3168}{1600}$$

$$\therefore f \times 692{\cdot}5208 = 627{,}723{\cdot}6 - b \times 1303{\cdot}374$$
$$f \times 210{\cdot}0399 = 190{,}387{\cdot}1 - b \times 395{\cdot}3104$$

Therefore, substituting the values of c and f in equation β,

$$b \times 7939{\cdot}806 - d \times 3906{\cdot}250 = -2{,}015{,}500{\cdot}58$$

Digitized by Google

This gives $$d = \frac{2,015,500 \cdot 58}{3906 \cdot 250} + b \times \frac{7939 \cdot 806}{3906 \cdot 250}$$

$$\therefore d \times 4236 \cdot 8285 = 2,186,069 \cdot 0 + b \times 8611 \cdot 738$$
$$d \times 330 \cdot 5785 = 170,568 \cdot 0 + b \times 671 \cdot 9308$$

Therefore, substituting in equation γ the values of c and d already obtained,

$$b \times 3669 \cdot 780 - e \times 330 \cdot 5785 = 846,627 \cdot 3$$

This gives $$e = -\frac{846,627 \cdot 3}{330 \cdot 5785} + b \times \frac{3669 \cdot 780}{330 \cdot 5785}$$

$$\therefore e \times 540 \cdot 6184 = -1,384,549 \cdot 0 + b \times 6001 \cdot 450$$

Substituting the values so found for e, d and f in equation δ,

$$b \times 5724 \cdot 8296 = 1,107,551 \cdot 0$$

$$b = 193 \cdot 4644$$

$$\text{and } b - a = 193 \cdot 4644 \quad \ldots\ldots\ldots \text{I.}$$

And since $$c = -\frac{109,366 \cdot 42}{3086 \cdot 420} + b \times \frac{3904 \cdot 7568}{3086 \cdot 420}$$

$$\therefore c = 209 \cdot 3251$$

$$\text{and } c - b = 15 \cdot 8607 \quad \ldots\ldots\ldots \text{II.}$$

And since $$d = \frac{2,015,500 \cdot 58}{3906 \cdot 250} + b \times \frac{7939 \cdot 806}{3906 \cdot 250}$$

$$\therefore d = 909 \cdot 2024$$

$$\text{and } d - c = 699 \cdot 8773 \quad \ldots\ldots\ldots \text{III.}$$

And since $$e = -\frac{846,627 \cdot 3}{330 \cdot 5785} + b \times \frac{3669 \cdot 780}{330 \cdot 5785}$$

$$\therefore e = -413 \cdot 382$$
$$\text{and } e - d = -1322 \cdot 5844 \quad \ldots\ldots\ldots \text{IV.}$$

And since $$f = \frac{1,450,293 \cdot 04}{1600} - b \times \frac{3011 \cdot 3168}{1600}$$

$$\therefore f = 542 \cdot 319$$
$$\text{and } f - e = 955 \cdot 701 \quad \ldots\ldots\ldots \text{V.}$$

And since $$g = \frac{417,799 \cdot 5}{434 \cdot 0279} - b \times \frac{594 \cdot 8838}{434 \cdot 0279}$$

$$\therefore g = 697 \cdot 445$$
$$\text{and } g - f = 155 \cdot 126 \quad \ldots\ldots\ldots \text{VI.}$$

$$\text{also } a - g = -697 \cdot 445 \quad \ldots\ldots\ldots \text{VII.}$$
$$g - b = 503 \cdot 981 \quad \ldots\ldots\ldots \text{VIII.}$$
$$f - c = 332 \cdot 994 \quad \ldots\ldots\ldots \text{IX.}$$

Digitized by Google

THE FOLLOWING PUBLISHED WORKS RELATING to the SUBJECT of the PAPER HAVE BEEN CONSULTED.

(1) Ordnance Survey. "Abstracts of the Principal Lines of Spirit Levelling in England and Wales." By Col. Sir HENRY JAMES, R.E. 1861.
(2) Ordnance Survey. "Abstracts of the Principal Lines of Spirit Levelling in Scotland." By Col. Sir HENRY JAMES, R.E. 1861.
(3) "Tables of Heights in Sind, the Punjaub, North-West Provinces, and Central India." Calcutta, 1863.
(4) "Tables of Heights in North-West Provinces and Bengal." Roorkee, 1866.
(5) "On the Methods of determining Heights in the Trigonometrical Survey of India." By J. T. WALKER, Lieut.-Col. R.E.—Royal Astronomical Society. Vol. 33.
(6) "Nivellement de précision de la Suisse," under the direction of Messrs. Hirsch and Plantamour. Five Nos., 1867 to 1874.
(7) "Nivellement Général de la France." Published by the Minister of Agriculture, Commerce, and Public Works.
(8) "Account of a Level Line measured from the Bristol Channel to the English Channel during the year 1837–8 by Mr. Bunt." Drawn up by the Rev. W. WHEWELL. Eighth Report of the British Association for the Advancement of Science. 1839.
(9) "A Treatise on the Principal Mathematical Instruments employed in Surveying, Levelling, and Astronomy." By FREDERICK W. SIMMS. 1836.
(10) "On the Algebraical and Numerical Theory of Errors of Observations." By Sir G. B. AIRY. Second Edition, 1875.

[Sir G. B. AIRY

Digitized by Google

Sir G. B. AIRY, Astronomer Royal, observed that, although he had run a few miles of level himself, he could not make any practical notes upon this communication; but he would say one thing, that, referring to the state of knowledge upon the matter as it was some years ago, something of this accurate character was much wanted. On one occasion he wished to know how far reliance could be placed upon the levels between Manchester and Runcorn, and applied to an engineering friend, who did not profess to be able to answer the question accurately, but referred to three others who were considered likely to be perfectly informed upon the matter; and one of these gentlemen said he thought the levels might be trusted to 6 inches, another put it at 2 inches, and the third at 1 inch. That was the state of things some years ago. No doubt they had grown better now; but still he was pleased to hear that there was an attempt at getting greater accuracy on this point, and by a collection of the best measures. Amongst those that had been brought together was that of Switzerland, with which, although less extensive than those of Great Britain and India, extraordinary pains had been taken. He had the good fortune to be personally acquainted with M. Plantamour, who was at the head of that, as well as with the officers at the head of the two other surveys, and he was quite sure that, in Switzerland, everything was done which could be done by men careful and well acquainted with the mathematics on the subject. As far as he could remark, there was but slight mention in the Paper of one of the discoverable errors, namely, that constant error which produced a difference in the apparent levels according as a line was levelled in one direction or in the opposite direction. This had excited attention a number of years ago on the occasion of levelling from the English Channel to the Bristol Channel. Amongst other causes assigned, he did not know whether there had been an allusion to the possibility of an error from the possible circumstance—for he was not sure that it was a real one—of always reading the front staff before the back staff, or the contrary; it was conceivable that that should cause such an error. With regard to the mathematics of the case, as applying to a geodetic survey, he was glad they were brought into shape, and he would point out the nature of the mathematics concerned. Supposing that levelling was effected in a triangle between these stations; it was to be expected in all cases that there would be some degree of inconsistency; but by proper treatment, understood by practical men, the determination of the most probable errors amongst them could be laid down, and the way in which the

Digitized by Google

inconsistency should be divided between the three stations. In another triangle, or a trapezium or polygon, the same could be done there; but suppose those were connected by other levels which joined one of the figures to the other figure, the problem was immediately changed. Neither of those could be treated separately if they were joined by levelling from the stations of one to the stations of the other. The problem came within the case which, in a little book that he had written upon the subject, he had called 'entangled errors,' and admitted of accurate treatment, leading to a definite result in every case. The best thing, therefore, that he could do was to recommend engineers to read his book.

Mr. LONGRIDGE said, although the Paper might not be of much general use to Civil Engineers, it was still one which in the higher operations of levelling, so necessary for other purposes, must be of great value. In their operations engineers did not require that extreme accuracy which called for the treatment of the subject in the way in which it had been dealt with by the Author. If the system of levelling was carried on with tolerable care, and properly checked, they would arrive at results which were quite as accurate as was required for such purposes as waterworks, canals, and railways. He was surprised that any engineer could have told the Astronomer Royal that between Manchester and Runcorn there might be as much difference in the estimated level as 6 inches; for in the days of the Liverpool and Manchester railway, when the instruments used were not like those of the present day, but something more like a mason's level, he did not believe engineers got further wrong than 6 inches. In his own early days, when levelling the North Midland railway, the system adopted was that the levels were checked by another person. If a difference was found of 2 inches in a distance of 30 miles, the work had to be done over again; and he could safely say, in a distance of 30 or 40 miles, if the levels did not check within that limit, the work was thought very bad indeed. If the ground was rough, there might be loss in going up hill; but the gain would be as much in going down, although it was quite true there might be an error at the top of the hill. Another error spoken of was that arising from the staff not being held vertically. Formerly the staves were made with levels and plumb-bobs in them. That, however, was perfectly unnecessary, and the only thing required was to instruct the staff-holder, when he held up the staff, instead of keeping it perfectly vertical, to move it backwards and forwards. The lowest level could then be read off. Another cause of error was from shifting the staff. To obviate that, he had small tripods, which the staff-holder pressed

Digitized by Google

with his heel into the ground and held the staff on, so that the staff was not shifted, but was simply turned round. No doubt all these details were well known to practical men. Referring to levelling instruments, he wished to mention one he had used with great advantage for some years, particularly in rough ground. It was, he believed, devised by Mr. Metford, and was made by Pastorelli. It differed from the ordinary level in not having parallel plates, but instead a ball and socket and three screws. The level had a circular bubble as well as the ordinary bubble, and it was set by using the ball and socket. Directing it upon the staff, it could be set almost exactly right, the bubble being adjusted by the slightest pinch upon the screw. It was done in a moment, instead of having the four screws to adjust, which was tedious on rough and sidelong ground. He believed a third of the time might be saved on rough ground by using such an instrument; and he therefore recommended it to those who wished to get through their work quickly.

Mr. Barlow, Vice-President, thought Mr. Longridge had hardly caught the sense of the Paper. There were sources of error, if he understood the Author, which could not be got over by checking by any person, arising, for example, from levelling from point A to B as compared with levelling from B to A. The Astronomer Royal had mentioned the levels taken from the Bristol Channel to the English Channel—from Portishead to Axmouth—a distance of 74 miles.[1] The instruments used were of the most perfect class, and the levels were done with every possible pains that could be taken for such work. The levels were taken for a Committee of the British Association, under the immediate direction of Professor Whewell, and in that case an error had been made at the end, comparing the levels taken from north to south with those taken from south to north, exceeding 1 foot. Starting from the northern end, in a distance of 12 miles there was an error of $\frac{36}{100}$ foot; in 27 miles, $\frac{57}{100}$ foot; at 43 miles, $\frac{75}{100}$ foot; and in the whole 74 miles, $1\frac{3}{100}$ foot. The gradual manner in which that error occurred from one end to the other showed there was something beyond that which ordinary levels professed to check. In the ordinary way of levelling, probably the man who took the check levels would follow in the same route as the man who took the original levels, and if so he would have found no error at all; but in levelling from one end to the other, and in reversing the operation and levelling back again, these extraordinary results

[1] *Vide* Report of the British Association for the Advancement of Science, vol. vii., p. 1 *et seq.*

Digitized by Google

were pointed out. He therefore could not help thinking the engineers who informed the Astronomer Royal of the possible error of 6 inches in 34 miles were not so far from the mark as they might be supposed to be.

Mr. LAW remarked that one source of error, arising from the varying temperature of the atmosphere increasing or lessening the length of the bubble, had not been referred to. From the way in which ordinary level-tubes were ground, it was almost impossible to insure their being such a perfect circle that the results obtained should be equally accurate when there was a short bubble and a large one occupying a much longer segment. For this reason, some years ago, Mr. Ramsden applied to a transit instrument a circular level, similar to a watch glass, which, being ground as true as a lens, gave more accurate results.

Mr. BINNIE said he was rather surprised that what he had found to be the most difficult error to estimate or to account for had been entirely omitted. If a person levelling, as he had done, in a tropical climate early in the morning, had occasion to level from east to west, or *vice versâ*, he would find the staff brilliantly illuminated at one stage, but at the other in comparative shadow. The result was that the eye did not readily accommodate itself to the difference of illumination, and it was curious, in levellings taken in the morning and again in the evening over the same ground, to notice the differences that would arise, due, as he was convinced, to a great extent to the unequal illumination of the staves when placed in those extreme positions. He had a line 10 or 12 miles, running east and west, carefully levelled with the best instruments by the best native observers, and was surprised at the errors taking place in that particular line. He tried it as an experiment on another arbitrary line running north and south, and the errors taken in the morning and evening, the usual time for levelling in India, almost disappeared. No doubt practised observers, eliminating their personal errors, would have reduced the error almost entirely, by varying the direction of the line with the illumination of the staff.

Mr. REDMAN suggested that the greater error shown for the English levels might possibly arise from the small amount of time usually allowed for such operations in this country, and the rough-and-ready way in which they were generally carried out. Some few years back he took check levels with the late Mr. Augustus Hamilton Bampton for the permanent levels of the Plymouth and Tavistock railway. Mr. Bampton had an expensive, large,

Digitized by Google

heavily-mounted instrument, while he used a small Simms' dumpy. On comparing notes the error between Plymouth and Tavistock amounted to 4 inches over 18 miles, which would give a value of 0·0185 foot per mile, corresponding very nearly with the third value set down for India in Table II. A series of levels had been taken in 1830 by Colonel Lloyd, R.E., whose levels were usually accepted as undoubted, and the benchmarks had been connected generally with the Ordnance Survey; the result then arrived at showed a difference of level between high water at London Bridge and Sheerness of 2 feet, whereas it was undoubtedly nearly 4 feet at that period as it was now. The discrepancy arose from the fact, that the levels were connected with a series of tidal observations that gave a higher range for the tide at Sheerness than was actually the case.

Mr. R. H. HILL observed that there seemed to be a possible error which had not been alluded to. Though certainly not a practical one for civil engineers generally, it might possibly come within the scope of an Astronomer Royal. In levelling from the equator to the pole, he imagined the line of sight was a tangent to an ellipsoid curve, and therefore that the offsets of that curve would not be equal. In levelling parallel to the equator the offsets would be strictly equal. What the amount of that error might be he was not in a position to calculate, but perhaps Mr. Airy, in his reply, would say if it was a calculable one in 400 or 500 miles, for instance, of levelling; and if so, whether he had taken it into account in the results he had given.

Mr. ELWES said one source of error which might possibly throw some light on that accumulating error, was the fact that, in levelling operations, two observations were always taken from the same staff, and that there was a perceptible interval of time between the first and second. Now, the weight of a levelling staff was not altogether to be neglected, and it had occurred to him, that the weight of the staff pressing upon the point of support, especially where a peg had not been driven in to carry the staff, might possibly lower its position, so that at the second reading it would be a trifling amount below what it was at the first. If ten observations were taken in a mile, and the error amounted only to 0·001 foot at each observation, it would give an accumulating error of 1 foot in 100 miles, which in the Irrigation Department in India, was considered the maximum difference to be allowed. This would equally apply, whether the fore staff was read first or the back staff, because in either case the second reading would be taken at an appreciable interval of time after the

Digitized by Google

first reading, and in that interval, more particularly if the staff-holder, in reversing the staff, lifted it up and let it fall, there might be a slight lowering of the point of support.

Mr. A. GILES remarked that his early days of levelling were connected with the old staff, when surveyors did not read their figures, but trusted to the staff-holder to move a vane up and down, and were dependent upon the accuracy of that man's movements for reading off the staff. He could not help feeling, as a practical leveller, that there were errors mentioned in the Paper which no engineer in levelling for a canal, or waterworks, or railway would ever take into calculation. In the Paper the maximum distance of the staff was put at 5 chains, and in India at 10 chains, but when accuracy to 0·001 foot was required the stations must be closer, since with an ordinary level the staff could not be read off to that nicety at 10 chains distance. If levels of such startling accuracy were required, the pickets must be firmly driven, nicely polished, and levelled off; they must be measured exactly equidistant from the level, and the engineer must never think of going out when there was the least breath of air to ruffle the instrument. There must also be plumb-bobs, and bubbles to keep the staff level. If an ordinary leveller were to be encumbered with these impediments he would never get through his work. He had frequently levelled 12 miles a day. He obliged his men to put stones down for pickets, and not to trust to the picket being carried down ½ inch by the simple weight of the staff. In going up or down an incline it was true the back stations in going up would be farther off than the fore stations, and if the level was not perfectly in adjustment, there would be a slight local error at the top of the incline, but, by the same rule, in going down again that error would be corrected. He maintained that for all practical purposes an error of only 1 inch in 10, 20, or 30 miles was quite near enough for any engineer to work to. No doubt, theoretically, it would be desirable to obtain absolute accuracy, but when he heard of a series of scientific levels having been taken between the Bristol Channel and the English Channel, which showed a difference of more than 1 foot, he should like to know on which line the error lay, and how it was corrected. No ordinary levelling by an instrument was exactly accurate, and the only course to prove its accuracy would be to take a series of levels from one side to the other and back again, and then to take the mean. He believed any practical leveller of the present day, with ordinary instruments, would be able to get much nearer than 1 foot of difference between the Thames and the Bristol Channel.

Digitized by Google

Mr. BARLOW said if he made use of the term "error," he should have said "difference." The matter was gone into with extreme care, and probably the mean of the two sets of measurements was more like the correct level.

Mr. J. N. SHOOLBRED stated, with reference to the apparent discrepancies appearing sometimes in very careful levelling, a case which lately came under his notice in the neighbourhood of Liverpool, where the levels had been conducted with the greatest precautions: he referred to the datum of the Ordnance levels for Great Britain, which had been fixed at Liverpool. There was also another of long standing in use there, called the "Old Dock Sill" datum. Though several well-known engineers had at different times levelled and compared the two systems, one would be surprised to find how much discrepancy there existed, amounting at least to between 3 and 4 inches, as to the actual difference of level between the two points of reference. This matter had been brought before the last meeting of the British Association at Bristol, and a committee, of which Sir William Thomson was chairman, was appointed to find out the real cause of the discrepancy.

Sir JOHN HAWKSHAW, Past-President, thought a little confusion had arisen in the discussion of this question; the point was not altogether what was sufficiently accurate for railways and ordinary engineering works. For a railway it could not signify much if in a length of 70 miles there was a difference of 1 foot in the levels. But there were operations where it did signify. For instance, the Ordnance levels were referred to the mean level of the sea, and to other standards which had to be ascertained; but if this mean level of the sea could not be ascertained with precision it might lead to considerable errors in some operations. With reference to the tides, although it was of importance to know what was the mean level of the sea round the coast of England, and in other and more distant places, he doubted whether it had yet been accurately ascertained. It was to purposes of that kind that Papers similar to the present had an important bearing. Going from that portion, he might mention one or two things with regard to practical levelling. In the first place, he believed, if his memory did not mislead him, with regard to levels which he had to take a long time ago, he was able to get a little nearer than some of the differences referred to; but that was very much a matter of instruments. He had a large instrument made by Troughton with which he could read to $\frac{1}{10}$ inch, at much more than 10 chains off; he believed to $\frac{1}{10}$ inch nearly $\frac{1}{4}$ mile off. He might mention a somewhat curious instance of comparison

Digitized by Google

betwixt ordinary rough levelling and levelling with more scientific instruments, which occurred to himself when he had occasion to go to Saxony, now forty years ago, in order, in conjunction with Mr. Walker, to lay out the Leipsic and Dresden railway. The then Astronomer Royal for Saxony had been engaged, before he commenced his operations, in making a section of the country. He had been three months in getting from Leipsic to Wurzen, about 14 miles; he used a large astronomical instrument, with which angles of depression and elevation were taken, and all the corrections that an astronomer could apply were made. When he got out to Saxony he was told that those operations were being carried on, but replied that it would be sadly too slow for his purpose, for he could not remain there above three months, the distance being about 70 miles. Starting, he ran over with a spirit-level from Leipsic to Wurzen in three days. They were only trial levels, but he wished to see the best line of country. He remembered quite well the difference betwixt the Astronomer Royal and himself was only 7 inches, showing that for common engineering purposes levels did not, perhaps, require to be taken with that minute care and accuracy which were certainly necessary for other operations.

Mr. Arthur Woods said he had levelled several thousand miles in Australia. On one occasion, for the New South Wales Government, he had occasion to run a line of levels 300 miles, which was checked independently by the Victorian Government. In the 300 miles the difference was only 0·12 foot. He put in benchmarks every mile, and for any difference over 0·06 foot, used to go over the ground a second time. Iron tripods were used to rest the staves on, and he should have considered it very bad levelling to have had an error of 0·28 foot in 5 miles.

Mr. Adie observed that no reference had been made to the refraction of light. He believed that if there was an error in levelling in one direction compared with levelling in the other direction, the probable cause, in some degree at least, must be from the refraction of light. This was explained to some extent, by the fact that the tables showed that the Indian levels were, on the whole, much more accurate than the English. Whether that was from the purer atmosphere, or not, he did not know, and the same indeed applied to the Swiss. In the transit of a star refraction did not matter, because it was equal on both sides; but it was not so in levelling, and probably this was the cause, in some degree, of the different results obtained in levelling in the different directions.

Digitized by Google

Major COURTNEY, R.E., observed, through the Secretary, that the method proposed by the Author, though certainly ingenious, and doubtless securing a high degree of accuracy, was, in his opinion, far too complicated and involved too great an amount of office-work to be of much practical use. Besides, from an inspection of the Indian levelling results, it appeared that, owing to the strict precautions used to prevent any large difference accumulating in the work of two observers, their results left little to be desired in point of accuracy, and this without all the laborious calculations of the proposed method. Their system of getting rid of cumulative errors in the field involved but little computation, and was far better for practical purposes. With respect to the English results being so inferior to the Swiss, he found that the latter, in order to get the best results, took the utmost pains, and used every instrumental refinement, even putting highly-trained officers on the work to make the observations. It was therefore only to be expected that their work should be superlatively good; on the other hand it must be far more expensive per mile. He thought this should be stated in fairness to the English work.

Mr. AIRY, in reply, drew attention to two levels lent by the firm of Troughton and Simms. One was an ordinary dumpy level, the other "The Italian Y level," designed by Mr. Simms according to a plan well known on the Continent. The latter had all the proper movements for easy adjustment in collimation, and the level was not, as usual, attached to the telescope, where it was liable to knocks, but to the frame, where it was much more sheltered. Levels of that size were not used for the standard levelling of countries: they were far too insignificant for that work; but they were convenient for engineering purposes. It had been remarked that the degree of accuracy mentioned in the Paper had little reference to ordinary engineering operations. That was perfectly true; but of course there was no reason why one should not search for greater accuracy than was ordinarily necessary, and for geodetical purposes—and the Paper was more directed to geodetical purposes than engineering works—a high degree of accuracy was necessary. It had also been said that errors caused by the waving of the staves, and so on, were not of great consequence, because if an error was made going up hill it was cancelled in coming down; so that if the operations were completed at pretty near the same level from which they had been started no large final error would have crept in. But in levelling over several hundred miles, going up to a height of several thousand feet, and down again, the top point was very likely to be a great

Digitized by Google

deal in error. No doubt Mr. Bunt's levelling, which Mr. Barlow had referred to, was quite historical in its way. It certainly was found out by Mr. Bunt and Dr. Whewell for the first time, that if levels were made in one direction to a distant point and then back again, different results were obtained—in fact, that there was a kind of orientation in levelling—that in levelling from north to south a different result was got from that obtained by levelling from south to north. That had been amply verified by Colonel Walker in India who, in one of his reports, described the source of the error, which he believed to be the most significant of all causes of error, and said: "A good deal of uncertainty exists in reading the level, owing to its being usually placed above the telescope and nearly in the same plane as the eye of the observer, who gets a side view of the bubble, which is never as satisfactory and sharply defined as the look-down view from above. The rim round the bubble, caused by the adhesion of the liquid to the sides of the tube, becomes so prominent, that in certain lights its extremities may be taken for the ends of the bubble. When light falls obliquely on the instrument, the outer edge of the rim towards the light is more clearly defined than the inner, while at the opposite end of the bubble the inner edge is most clearly defined. Hence there is a tendency to bring the bubble too much towards the light, and give the readings an erroneous bias, which some observers might guard against more than others." That was how Colonel Walker explained the difference of the results obtained in going in one direction or another. With regard to the error arising from the effect of temperature on the length of the bubble, he did not think that it would be sensible with the best modern levels. In the Swiss levelling, and in the Indian levelling, the ends of the bubbles were always read. There was never any question of setting the bubble exactly true. It was set true within certain limits, and then the ends were carefully read and booked, and corrections applied for the amount it might be out of truth, so that there would be little uncertainty arising from that source. Mr. Binnie remarked that there was an error due to the unequal illumination of the staves on going from east to west, or in any way in which the light fell very sharply. To reduce this short reads must be taken, so that the unilluminated staff could be read as clearly as the illuminated one. This would make the work a little slower. It was an error that came under the head of genuine errors of observation, and no doubt was included in the figures he had exhibited. Mr. Redman remarked that no doubt the reason why the English levelling

Digitized by Google

showed badly as against the Indian and the Swiss was because it was executed in a hurry. He believed that was the case; but at any rate the English levelling was begun in 1844 when people did not understand levelling so well as now. The care given to the levelling in India and Switzerland was extraordinary, but the English levelling was comparatively antiquated. With reference to what Sir John Hawkshaw had said, he should have considerable doubts of any results or calculations referring to the mean level of the sea around England, as deduced from the English levelling. The levelling was not good enough to prove things of so much importance, and the levels required to be checked over and over again with superior instruments and care. He did not think that any sensible error could arise from the elliptical form of the earth. The weight of the staff, no doubt, would operate if the ground was soft; but in all standard operations much more care was used than to place the staff on soft ground. In India a peg was driven for every position of the staff, and so each peg became, as it were, a benchmark. The succeeding observer who checked the work invariably put his staff on the same pegs, and so there was absolutely a benchmark from reading to reading the whole distance, and if a mistake crept in it could be located immediately and rectified. The Australian levelling mentioned by Mr. Arthur Woods undoubtedly was very good, and was on a par with modern good levelling, as shown in the Paper. With respect to Major Courtney's remarks, he would state that the closing error of an extensive system of levels, however carefully the work was done, was almost certain to be too great to be disregarded, and needed to be dealt with in a formal manner. There was no short cut to such adjustments, and it would be seen by a reference to their reports that the Swiss engineers devoted an immense amount of labour to the adjustment of extremely small errors.

Digitized by Google

Sect. II.—OTHER SELECTED PAPERS.

No. 1,436.—"The Lagoons on the South-east Coast of Ireland." By George Henry Kinahan, M.R.I.A.

A description of the lagoons and banks on the south-east coast of Ireland, with suggestions as to their origin, may be interesting to the members of the Institution, as a supplement to Professor Prestwich's Paper, "On the Origin of the Chesil Bank."[1]

The lagoons to which attention is directed all lie between Brattin Head, co. Waterford,[2] and Cahore Point, co. Wexford[3] (Plate 7). These include the Tramore lagoon, called the "Back Strand," co. Waterford, and those in co. Wexford, called Ballyteige Lough, Tacumshin Lake, Lady's Island Lake, and Wexford Harbour. Reference will also be made to Waterford Harbour and Bannow Bay, and suggestions given as to the reasons why lagoons did not form in them also. Bannow Bay, indeed, might be called a lagoon, but it is very different to the others mentioned. Previous, however, to entering into the subject of the lagoons, it will be necessary to give a short résumé of the geology of the country.

In these portions of the counties of Waterford and Wexford, granite and other igneous rocks occur, with derivate or sedimentary rocks, of the Cambrian, Cambro-silurian, and Carboniferous ages, partially covered with more or less recent drifts. The older Palæozoic rocks are partly metamorphosed, and much broken up and displaced by faults; the Carboniferous rocks are faulted in a less degree; while the drifts are only slightly disturbed. The drifts may be classified as follows:—Glacial drift. Sands and other marine accumulations formed during the Esker period, when the sea stood about 350 feet[4] higher, relatively to the land, than at present. Sands and other marine accumulations of the "age of the 100-feet[4] sea beach," when the sea stood for some time between 90 feet and 120 feet[4] higher than at present. Sands, &c., of the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xl., p. 61.

[2] Admiralty Charts, Ireland, sheet xiv. [3] *Ibid.*, sheet xv.

[4] These heights are above the Ordnance datum, not above the mean tide; consequently, on some portions of the coast of Ireland, when the tide rises high, these ancient sea beaches seem to be at different levels.

Digitized by Google

"age of the 25-feet sea beach," thrown up when the sea was stationary, between 20 and 30 feet higher than at present. Estuarine accumulations; and, finally, more recent drifts.[1]

The present lagoons, although their basins were probably formed during the "age of the 25-feet sea beach," occur on the sites of very ancient hollows or valleys. Subsequent to the metamorphism of the Cambro-silurian rocks, but prior to the Carboniferous rocks being deposited, denudation excavated valleys and hollows in the pre-existing rocks, along lines of weakness principally due to faults, breaks, and shrinkage fissures. These hollows were more or less filled up by rocks of the Carboniferous age; and between the end of that period and the dawn of the Glacial, the newer rocks were also faulted, and other valleys eroded, all to be afterwards partly or wholly filled by glacial accumulations. Of the glacial drifts, a considerable portion seems to have been denuded and rearranged, during the "Esker sea period" into shingle, gravel, and clay; and those at low levels still more recently, while the sea was stationary at about 100 feet, and at about 25 feet higher than at present. During both these latter times, drift of the Esker period was also denuded, the bays now lagoons having been excavated principally in it and the newer drift, during the "age of the 25-feet sea beach." For then, as now, the sea cliffs from Cahore Point to near Bannow Bay were principally formed of drifts belonging to the Esker period, or 100-feet beach age, while those to the west of Bannow Bay were more or less hard rocks. After the "age of the 25-feet sea beach" the land gradually rose until it was at least 30 feet higher than at present, at which time the bays were filled by estuarine or land accumulations. Afterwards the land slightly sank.[2] None of the lagoons, here or elsewhere in Ireland, are in the deltas of rivers, from the nature of the river valleys; as the detritus brought down by the head-waters and mountain tributaries of the large rivers is deposited in one or other of the flat reaches along their courses, and little or none of it is brought down into their estuaries. Thus the bars of these lagoons have a different origin from those in the South of France along the margin of the tideless Mediterranean sea.[3]

---

[1] The ages of the drifts have been discussed in a Paper by the Author on "Glacialoid or rearranged Glacial Drift" ("Geological Magazine," March and April 1874).

[2] *Vide* Paper on "The Estuary of the Slaney," read, March 1875, before the Royal Geological Society, Ireland.

[3] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 287.

Digitized by Google

Some of the lagoons have permanent open channels through their inclosing banks; while the outlets from others are temporary and changeable, being at one time open, at other times closed, and variable as to position. The origin of the banks is apparently due to the effect, at the different periods of rest, of a tendency of all gradually subsiding, or of sometimes rising tidal seas to form a terrace at high-water mark. On open coast lines, all marine denudation on the cliffs seems to be accomplished by the incoming tidal waves, this being at its maximum when assisted by storms. But the drifting of materials to fill up hollows is a distinct though concomitant operation. The operation of three distinct forces transports the materials, namely, that of the incoming tidal waves, that of the waves formed by winds in shallow water, and that of the wind carrying materials on the land. The first has usually the greatest influence, as it acts twice daily, while the others can only be in force during gales and storms; wind also forms the ground swells. If the prevalent winds on a coast blow in the same direction as the set of the "flow" tide, both act in concert, and the drift is increased accordingly. If, however, they act in opposite directions, the effects of the wind temporarily modify the effects of the tidal waves; but as one is a daily worker, while the other acts only occasionally, all the work done by the wind, within reach of the tidal waves, is more or less obliterated. It is remarkable, even during heavy gales, how much power the incoming tidal waves have, compared with that of the waves raised by the wind. This was exemplified in Ballyteige Bay, during the winter of 1873–74, while the iron vessel "Calcutta" was beached broadside to the shore. The wreck was visited a week after it had been driven ashore, during which time a steady, heavy gale had blown from the W.S.W., in a different direction to the incoming tidal waves, which here set from the E.S.E. During this week a considerable sandbank formed between the vessel and the shore, the major portion of the sand being banked behind the W.N.W. end of the vessel, while there was scarcely any sand behind the E.S.E. end, which showed that the drift from the tidal waves was greater than that of the wind waves.

Wind when acting by itself has considerable power, and to it are due the height and character of many of the lagoon banks, as during low water it carries from the exposed shores a large quantity of sand above the reach of the waves, while the materials in the banks are drifted thereby from one place to another, and piled in high hills and ridges, sometimes from 50 to 100 feet high, or even

Digitized by Google

more. The wind often, however, modifies its own work, as the sand driven up by one gale may be carried to sea by another from a contrary direction.

When the sea-margin is denuded into a flat, a few feet higher than the strand, it forms a rampart or beach, of shingle, gravel, sand, or seaweed on the margin of the flat. This, although ever slowly retreating backwards, is still, as a general rule, growing higher and higher from the drift of the waves and wind; while behind it water may collect from land drainage or the sea going over the bank during storms or high tides, and thus many lagoons are formed. Some bays are gradually filled up with slightly sloping muds or strands, while others change into lagoons. The latter change in some is due to a shoal forming off a shore-reef, which afterwards is modified into a spit, that gradually increases in length, until eventually a bank incloses a lagoon. Other bays seem to change into lagoons on account of a river or stream flowing in a contrary direction to the waves of the incoming tides; consequently a shoal, and eventually a bank, appears at the meeting of the currents, which increases in length until a lagoon is inclosed. Other lagoons seem to be due to off-shore shoals, being modified into bars as the land gradually rises.

From the above description of the origin of the inclosing banks of lagoons, it is apparent that they can be formed during either the falling or the rising of the relative level of the sea.

Whichever of the above processes may have given origin to the inclosing bank of a lagoon, the lagoon itself is, all the while, being gradually silted up. This in the Irish lagoons, on account of the nature of the river valleys as previously mentioned, is rarely promoted much by the wash from inflowing streams. The lagoons do, however, receive a little from the waste of the marginal lands; but they seem to be principally filled by detritus carried into them by the sea during storms and high tides, or by materials drifted into the basins by the wind; the wind, however, will often modify its work by blowing out again some of the sand. This, especially in some localities, takes place in hot summer weather, when the evening off-shore winds blow over dry portions of the lagoon bottoms. In some lagoons a small part of the material consists of minerals deposited from the water when evaporating; while in favourable situations marshes will form, which eventually change into peat bogs.

Some bays do not form lagoons, as for instance, Dublin Bay. In this bay, but especially towards its head, circumstances would seem to have been favourable for the formation of a lagoon. There

Digitized by Google

indeed appears to be an incipient bank;[1] but this has evidently lost its original condition, on account of the artificial works from time to time executed in the bay. In rock-bound bays there seems to be a scarcity of materials to produce a bank; while in some long, narrow bays, especially if a large stream or river flows into them, although materials are plentiful, it is impossible for a lagoon to form; if the shore of the bay opposite to the drift of the incoming tidal waves is of such hard materials that it resists denudation, and consequently the stream channel cannot be obliterated and moved backwards before the advance of the inclosing bank, but the outcoming waters are forced to act on the materials carried in by the tide, and to spread them out more or less. On this coast Waterford Harbour belongs to this class, being rock-bound on its east shore opposite the drift of the incoming tidal waves. Consequently a bank cannot grow out from its western shore, the river channels not being able to cut into the shores and move eastward. Near the mouth of Waterford Harbour a bank has commenced to grow from the west shore opposite Broomhill; but the force of the ebb tides, combined with that of the waters of the Suir and the Barrow, has spread the material out, producing shoal water between Duncannon and Woodstown strands. At Bannow Bay a bank has grown from the western shore towards the north-east, from the headland, on the south-west of Bannow Island, and deflected the channel of the river, first due east, and then close to the shore of the island. Between the island and the mainland shingle beach has been cast up by the sea. In this bay a typical lagoon would have formed long since, but for the rock-bound island and rocky shore which prevent the channel of the stream moving eastward. Consequently the bar cannot exceed its present limits.

The Back Strand at Tramore.

The most westerly of the lagoons to be described is that called the Back Strand, at Tramore.[2] This occurs in the site of an ancient valley, as, prior to the Glacial period, a deep hollow, denuded in faulted and broken ground, extended from the town of Waterford to Tramore Bay. This valley was filled by glacial drift, while subsequently it was partly re-excavated during the "Esker" and "100-feet beach" seas, as the drift in the hollow

[1] Clontarf and White Banks, Chart Dublin Bay.

[2] Charts, sheet xiv.

Digitized by Google

was more susceptible of denudation than the adjoining rocky coasts at Newtown and Brownstone Heads. The present lagoon was probably for the most part excavated during the "age of the 25-feet beach," as in various places around it traces of the raised beaches can be found.

On this part of the coast the drift from the incoming tidal waves is from west to east, while the more prevalent wind-formed waves set in the same direction, consequently there is a general eastward drift of the banks. It would seem probable that when the land rose relatively after the "age of the 25-feet sea beach," the bay became filled with alluvium and bog, while subsequently, when it again came under the influence of the sea, a shingle beach was cast up along the margin of the flat, which in time, by the processes previously described, became the inclosing bank of a lagoon. Shoals could scarcely ever have existed in the bay, to be modified into a bank, on account of the hard nature of the coast to the westward, and consequently of a paucity of materials to form them. The site of the bank must have been originally much more seaward, as peat and estuarine accumulations occur outside it.[1]

The streams flowing into the lagoon would never have been large, consequently the washing from them has always been small. The principal one flows into the eastern side of the lagoon, so that the channel from the lagoon was probably always at the east end of the inclosing bank. In this and all the banks hereafter mentioned, the materials are principally Æolian or blown sands, derived from drifts. When, however, sections are cut into them by the sea, they seem to have a foundation of shingle or coarse gravel.

Ballyteige Lough.

The next lagoon, to the east, comprises the Ballyteige Lough and Broadwater. These exist on the sites of Pre-glacial valleys, as an ancient hollow extended up Duncormick Bay, and a second up Broadwater. The valleys seem to have had vicissitudes similar to those mentioned as happening at Tramore Lagoon, and subsequently, when the land rose after the "age of the 25-feet sea beach," there seems to have been a bay extending up to Duncormick, and a second through the Broadwater to near Bridgetown, with an island (Inish) opposite the mouth of the

[1] Peat is said to be found in deep water in the bay, but of this the Author has no personal knowledge.

Digitized by Google

latter. Here also the "flow" tide runs from west to east; yet, on account of the Saltee Islands, and various rocks and shoals off Crossfarnage Point, there is an inland current running about from east-south-east to west-north-west, which causes the main drift of the lagoon bank to be in that direction, although the drift due to the waves formed by the prevalent winds should be the opposite way.

The origin and time when this bank was formed are uncertain; evidently at one time the Broadwater formed an independent lagoon. Of the present lagoon bank, the western end is much newer than the eastern, as it is daily extending westward, the stream channel retreating before it, as the coast opposite is boulder-clay drift, which is easily denuded. From the appearance of the ground it seems probable that the present lagoon did not formerly extend as far west as Duncormick Bay; but that afterwards, on account of the drift of the bank towards the westward, it grew beyond the mouth of that bay and gradually reached its present extent. It cannot, however, go much farther in the present direction, as the boulder-clay drift, a little to the west, is replaced by Cambro-silurian and other rocks.

The bank of this lagoon may have begun as a spit on the shore rocks near Crossfarnage Point, and gradually grown towards the north-west, across, but off, the mouth of the bay of Broadwater, after which it was deflected westward, margining the coast. It appears, however, more probable, that, after the last elevation of the land, when it was sinking, and again came within the influence of the tidal waves, there was a low flat, on the margin of which a beach was formed, which gradually grew into a bank on account of the drift from the east-south-east, the bank at first extending from Crossfarnage towards the north-west, but since having slightly moved inland, and extended toward the west, margining the land.

It has already been pointed out that the main drift of the sand is from the east-south-east, while the drift due to the prevalent winds and wind-waves is in a contrary direction. These, consequently, at times, have acted against one another, and the effects have been, that, although the main channel from the lagoon seems always to have been to the west, yet, at times, other embouchures have opened through the bank during storms. Such channels were at one time open, but at others closed by the drift of the tidal current.

This lagoon, from the narrows a little east of Duncormick Bay, eastward, has been reclaimed during late years; but the reclamations have not been as successful as might have been expected.

Digitized by Google

Tacumshin and Lady's Island Lakes.

Between Crossfarnage and Carnsore Points are the Tacumshin and Lady's Island Lakes.

They are similar to the lagoon of Ballyteige, as they occur in the sites of ancient hollows, and, although in part excavated during the "age of the 25-feet sea beach," yet, so far as known, there is nothing against these inclosing banks being very recent, and having been piled up by the action of the present sea; but the depth and nature of their estuarine accumulations have not been ascertained. The banks, however, must originally have been farther seaward, as under them and outside are peaty estuarine stuffs; besides, hereabouts the sea is rapidly encroaching on the land, and, as it cuts away the cliffs, it moves the lagoons' banks back.

On this portion of the coast the drift of the banks is complicated on account of the prevalent winds blowing from the south-westward, while the drifting action of the incoming tidal waves is in various directions; during flood tide, the current inshore being westward for more than half the tide, while for the rest of the tide it is eastward, and this varying in the spring and neap tides. At Lady's Island lagoon there is no regular embouchure, while at Tacumshin the channel is often closed up. At Tacumshin there is a considerable stream flowing into the north-west part of the lagoon at Tomhaggard. This follows a channel, locally called a "pill," obliquely across the muds nearly to the east of the basin, where it turns at a right angle and meets the bank at its centre, proceeding thence along the bank to the west end. From this it would appear that the principal drifting of the bank is from the east towards the west. The west channel seems generally to have remained open; nevertheless it has often been closed up, on account of artificial cuts being made in other places.

Into the Lady's Island lagoon only small streams flow, and, as they do not contain sufficient water to keep any particular channel permanently open, they often close quite rapidly, to be opened again, sometimes in the old, but more usually in new places. Such channels may be cut by the dammed-up water when it rises too high, by high tides, by storms, but more generally by the hand of man. The inclosing banks of both these lagoons probably originated as beaches on the margin of flats; that at Tacumshin appears to have increased afterwards principally from east to

Digitized by Google

west, while the bank at Lady's Island Lake may have grown similarly or been piled up from seaward by the action of the waves and wind. A fruitless attempt has been made to reclaim Tacumshin lagoon, and since then the driftage of the bank westward has been considerable.

Formerly some lagoons existed between Carnsore Point and Greenore, but their inclosing banks have been pushed far inland and only traces of them remain, consisting of small bogs or marshes behind ridges of Æolian drift, with submarine bogs to seaward.

Wexford Harbour.

The last lagoon to be mentioned is the estuary of the River Slaney, known as Wexford Harbour. With the silting up of this lagoon, and the formation of the inclosing bank, the Slaney can have had very little to do, as the river brings down only small quantities of detritus into its estuary. This lagoon, like the others, occupies the site of an ancient valley. One, by geological evidence, existed here before the Carboniferous period, while the present lagoon was a bay at the "age of the 25-feet sea beach," having been excavated in drifts belonging principally to the "Esker" and the "100-feet beach" periods. Here, as elsewhere, after the "age of the 25-feet sea beach," the land rose relatively till it was at least 30 feet higher than at present, which is proved by the submerged peat in the lagoon and the submarine bogs out to sea. This ancient peat is recorded from the following places:—at the west engine-house on the North Flats, or "intake" (in the north-west part of the lagoon), bog 5 feet thick was found 16 feet below the surface of the mud, or 21 feet below the level of high water. The bogs at Curracloe and Ballinesker to the north-east of the lagoon are said to have been proved 20 feet deep, but here the peat was not "bottomed," as at that depth, turf, mud, and water burst up in the bogholes and flooded out the turf-cutters. Peat also exists off the shore under a depth of 4 fathoms of water between the main land and the shoal called Rush Bank, to seaward of an ancient lagoon south of Cahore, now a bog and marsh.

The Wexford lagoon is separated from the sea by two banks; one extending in a gentle curve northward from the Rosslare Coastguard Station to Rosslare Point, and the other in a curve southward from Ballinesker to Raven Point; the extreme length from the land on the south to that on the north being 10·5 miles.

Digitized by Google

These banks are of Æolian drift, as is also for the most part the spit of land to the south-west of the Rosslare Bank, but not entirely, as the portion next the South Flats is sand, gravel, and clay, probably accumulated during the "age of the 25-feet sea beach." Of the area inside these banks considerable tracts, to the south (South Flats), and to the north (North Flats), have been inclosed within the last thirty years; but, before this was done, in the north part of the lagoon there were several islands, principally masses of the "Esker period" drift (marl), that had escaped the denudation of the sea of the "25-feet beach," while, in the Raven Bank, there were three breaches through which boats could pass at high water. There is also a tradition that formerly the principal channel into the harbour had its embouchure at Curracloe. On this coast the main drift is from south to north, in the direction of the incoming tidal waves.

Possibly the banks that now divide the lagoon from the open sea may have begun as shingle beaches on the margin of a flat; but probably during the "time of the 25-feet sea beach," when the marine conditions and operations were nearly the same as they are now, there must have been, as effects thereof, off-shore shoals somewhat similar, but more inland, to those that now exist between Greenore and Cahore Points. Such shoals, as the land rose and the inshore current of the tide decreased in force, would be moved inland, and eventually modified from detached shoals into more or less continuous banks; and if the present sea bottom relatively was elevated 42 feet (7 fathoms) somewhat similar banks would be formed, crossed by two well-marked channels, one opposite the embouchure of Wexford Harbour, and the other to the north at Rush Channel. If, therefore, during the "time of the 25-feet sea beach," shoals existed off the mouth of the inner bay, they, as the land rose, would be modified into banks, through which there would be channels, the deeper probably being at the centre and to the northward. That at the centre ought to become deeper and deeper as the land rose and the outflowing current had increased power of denuding, while the north channel would silt up from the drift of the sand.

When the banks were formed they inclosed a lagoon which afterwards became a marsh, and eventually a peat bog; while subsequently, as the ground gradually sank, the sea began to flood the land inside the banks, the water at first flooding the bog in the vicinity of the channel, and afterwards extending, till eventually most of the old area again became a lagoon; not, however, all, as the banks were gradually moving in on the bogs; while portions,

Digitized by Google

such as the bog of Curracloe, to the north-east, were never flooded, but continued growing from the time when peat began to form in the lagoon to the present day.

As the sea rose, the banks moved inland; and since the land ends of these banks could not retreat as quickly as the open portions, and as the points of each bank at the central channel were also kept back by the force of the water flowing out of the lagoon, they necessarily form gentle curves. The previously mentioned breaks or shallows through the north portion of the banks, between the Raven Point and Curracloe, were probably kept open by the more prevalent wind-waves on the waters of the lagoon, as, since the north flats have been reclaimed, the drift of the sands northward has closed them up.

The Rosslare Bank of late years has been much denuded and in places breached; this seems in a great measure to be due to the back "counter" current generated by the present form of the Dogger Bank.

Previous to the reclamation of the North and South Flats, the outflow from Wexford Harbour was much greater than at present, and its force seems to have been about equal to that of the incoming tidal waves, consequently the Dogger Bank, as represented in Commander Fraser's chart (1844), Plate 7, was a massive sand-bank, due east of Rosslare Point. Now, however, it appears, from Staff-Commander Kerr's chart (1873), that within the last thirty years, since the outflow from the lagoon has been lessened by the reclamation of the Flats, the incoming tidal current has changed the Dogger Bank from a massive shoal to a long, narrow bank extending nearly south-west and north-east, overlapping the south end of the Raven Bank. On the Dogger Bank, a long, narrow island has been piled up across the site of a former channel; while the Hantoon channel between the bank and Rosslare Point is nearly silted up, and off the land the Lucifer shoal is gradually being carried away.

The study of the drift of sand on a sea-coast, and the growth of the inclosing banks of lagoons, seems of importance not only to the geologist, but also to engineers, otherwise great labour and cost may be incurred to no purpose, while reclaiming lagoons, or improving the embouchures of harbours. Consider the case of Wexford Harbour. The northward drift, as just now pointed out, is always bringing up materials, part to increase the dimensions and length of the Dogger Bank, and part to supply the materials for the "shifting sands" of the bar. To improve the entrance, it would be necessary to stop this drift, as much as possible. As the

Digitized by Google

main drift of the sands is known, this, in a great measure, might be accomplished by erecting a groyne, or breakwater, from Rosslare Point eastward across the Dogger Bank, on the south side of which all the drift due to the incoming tidal waves would lodge, the only materials left to form the "shifting sands" being the drift due to wind, or brought by the outflow from the lagoon. Such a groyne, for a long time, would effectually stop the tidal northward drift; but eventually, when the ground behind it was silted up, it would be necessary to increase its length, as otherwise the sands would creep round it. The groyne should be concave to the driftage, or have transverse groynes from it, as it is apparent from structures already made that if convex, the sand in a short time creeps round it.

In general groynes are very costly, consisting as they do of strong stone ramparts. These, however, are often destroyed by their own weight, and even if effectual, are in a short time buried in sand or other drift. To stop the drift, in many places, it is only necessary to make an impediment, as a nucleus, which subsequently would grow into a permanent breakwater. The combination of piling and sheeting is effective for this purpose in many places on the south-east coast of England; or fascines might be used, as seems to have been a custom with the ancient Irish. Even at the present day the latter have served to repair breaches in river and tidal embankments after piling at vast expense had failed.

Now to refer to the connection between the drift of sand and the reclamation of lagoons. At Ballyteige Lough the reclamation of the flat has not been so effectual as might have been expected. The works to reclaim the flat were a canal from Bridgetown to Duncormick Bay (B to A), to catch and divert the land drainage; an embankment across the narrow part of the lagoon, east of Duncormick Bay, in which there are tidal sluices to drain spring and surface waters off the reclaimed land; and the heightening of all low parts of the bank to prevent the sea coming in. At first these works appeared to be sufficient; but, on account of the flats being cut off and the area of water diminished, the outflow in the narrow portion of the lagoon between Duncormick Bay and Barmouth is now unable to carry away the sand blown or swept by the tide into it, consequently it has greatly silted up, and the fall is insufficient to drain the flat. The rise and fall of the tide outside the inclosing bank is 13 feet, while in the narrow between Duncormick and Barmouth it is 6 or 7 feet; it is therefore proposed to run a canal from the centre of the flat to Crossfarnage Point (D

Digitized by Google

to C). Another plan may be suggested, namely, a canal across the sandbank south-west of Richfield (in the vicinity of the line E F). The mouth of such a canal would be liable to be closed by, first, tidal drift from the east-south-east; secondly, by the wind-wave drift from the west-south-west, and, thirdly, by the land drift due to wind blowing the sand into it. The first of these might be prevented by erecting two or three groynes at intervals to the east of the mouth of the canal; the second, probably, by one groyne erected on the west of the mouth; and the third by planting belts of the Pinus Austriaca (the Austrian, or black pine), that have been found so effective to stop the blowing sands at Bundoran, co. Fermanagh, or by a box tunnel through the sand. Such a canal would involve a comparatively small cost, and it would start from nearly the lowest part of the flat.

In the attempted reclamation of the Tacumshin Lake, no catchment canal to carry off the land drainage was made, or no account seems to have been taken of the drift of the bank; therefore the latter silted up the embouchure, and the former flooded the reclaimed lands. On account of the drift in opposite directions on this part of the coast, different schemes might be suggested for reclaiming this lagoon.

The majority of those who took part in the discussion on Mr. Prestwich's Paper considered that the main drift of sea beaches is due to wind waves. This is contrary to the Author's observation,[1] and apparently to the results of the experiments on waves made by Mr. J. Scott Russell, M. Inst. C.E.[2] This eminent observer classes the great tidal wave in the "Waves of the first order," or "Wave of Translation," while storm waves nearly all belong to the "Second order," the exception being those portions that break on a coast beach, which then change to a wave of the first order. Mr. Scott Russell also shows that waves of the second order have little or no carrying power; consequently the only portion of the wind waves that can affect drift are those that have changed to waves of the first order, which necessarily are very local in their action.

Even on a coast that has not been carefully studied, the prevailing direction of wind and the normal direction of the drift of the sea beach can be seen at a glance. The prevalent direction

---

[1] *Vide* "Tidal Currents *versus* Wind Waves," read before the Royal Irish Academy. Proceedings, vol. ii., ser. ii., No. 5, January 1876.

[2] *Vide* Report of the British Association for the Advancement of Science, 1844, p. 311.

Digitized by Google

of the wind being indicated by the leaning of the trees, and the normal condition of the drift of the sea beach by the double-knee at the mouths of the streams; which are often in contrary directions.

On the shore of Lyme Bay there can scarcely be drift in two directions, as the meeting of the currents would form a "race," while the two drifts would run the shallow soundings out seaward, and possibly might form an off-shore shoal; the last, however, is not a consequent result. Neither does it appear possible, judging from the present condition of the Chesil Bank, that the large shingle could be drifted along the beach from north-west to south-east, because the pebbles decrease in size from the south-east to the north-west. This conclusion seems evident as large pebbles, in the ratio of their size and weight, are carried higher and farther along a beach than smaller and lighter ones. This can be seen by watching wave action. A large pebble if set in motion by a wave, is carried along with it, but when the wave retreats the pebble is left behind, while the small fragments, although carried also by the wave, are drawn back by the "backwash:" thus the larger get higher up and travel faster than the smaller ones. Off Beer Head there is a "revolving tide" (Admiralty chart, England, sheet iii.), the "flow" tide splitting; part running to the north-east, part towards the east, while a "drain" runs nearly due south. This must prevent a continual drift along the beach from Budleigh Salterton to Chesil Beach, therefore the pebbles of the Chesil Beach probably come from the south-eastward, across the bay in the tidal current. Mr. Scott Russell has proved that a wave of the first order on entering a sheet of water does not diffuse itself equally in all directions, but that in one direction there is an axis along which it "maintains the greatest height, has the widest range of translation, and travels with the greatest velocity." The tidal wave divides after passing Start Point, the main current making nearly direct to Portland, while branch currents feather from the main current north-eastward towards the shore. But the directions of the branch currents are complicated on account of the bays and estuaries between Start Point and Axmouth. It has been proved by observations that the tidal current increases from Start Point to Portland Bill, as the "flow" tide approaches the "nodal" or "hinge line" of the tide in the English Channel; which lies between Swanage Bay on the English coast and a point west of Cape Barfleur, this line being also where "the tidal stream is greatest." If the on-shore offshoots increase in the same ratio the main current would carry in it

Digitized by Google

the larger pebbles, while its offshoots, as they gradually decreased in power toward the west, would drift smaller and smaller fragments. By such a process the shingle from the ancient sea beach would be largely imported into the Chesil Bank, as the "raised beaches are of frequent occurrence between Plymouth and Torquay." Also as the south-east end of the bank near Chesilton is exposed to the force of not only the tidal wave, but also of the most effective wind waves, the largest and highest beach ought to be cast up at that place.

In Wexford Bay, between Greenore and Cahore Points, the normal course of the tidal wave is from south to north, while the most effective storm waves occur when the wind is blowing from north-east to north-north-east. The beach is fine gravel or sand except in a few places, but for the 3 miles south of Cahore there is a well-marked shingle or coarse gravel beach, and in this beach are found numerous rock fragments that must originally have come from Greenore Point or from the country to the south of it near Carnsore. These seem all to have come across the bay in the tidal wave, or from the Dogger Bank, north-east to the Blackwater Bank, and along the latter northward, as no pieces of the Greenore and Carnsore rocks are found on the beach between the Dogger Bank and the Cahore shingle beach. Some, possibly, may have come in the older drift (boulder clay); this, however, seems improbable, as in the old drift can only be found fragments of rocks that occur in the country to the north or east, and never of those to the south. During the winter of 1875–76 the continuous and heavy winds from the north-east stopped the northward driftage, and forced the sand into the north channel out of the Wexford lagoon; raising its bed, so that it is nearly impassable to the shipping frequenting the port. The water from the lagoon has however opened a new channel, nearly on the same site as one that existed prior to 1845. This new channel has been marked on the Admiralty Plan of Wexford Harbour (A.D. 1873), by Mr. T. Winder, Engineer of the Ballygeary Harbour Works.

This communication is accompanied by a series of Charts, from which Plate 7 has been compiled.

Digitized by Google

MEMOIRS OF DECEASED MEMBERS.

GENERAL CONSTANTINE TSCHEFFKINE, a descendant of the Cossack Prince Andreas Tchefka, was born in the government of Nijni-Novgorod, Russia, in 1802. After being educated at the Imperial Military School of Pages at St. Petersburg, at the age of twenty he entered the army as an ensign in the Imperial Foot-guards. In the course of a short but brilliant military career, Tscheffkine took part in the Persian and Turkish wars in 1826 and 1829, and so distinguished himself that at the close of the latter in 1830 he had already obtained, when scarcely twenty-nine years old, the rank of Major-General, and chief of the staff of Field-Marshal Diebitch Zabalkansky. After the Polish campaign of 1831, in which he likewise took a prominent part as chief of the staff, General Tscheffkine, although remaining until his death connected with the army, practically forsook the life of a soldier to serve his country in a wider sphere. In 1833 the Russian Imperial Corps of Mining Engineers was established on a military footing, General Tscheffkine being appointed chief of the staff of the new organisation. Having always had a partiality for geological and mineralogical studies, he applied himself to the performance of his new duties with activity, personally visiting the rich mineral regions of the Ural and the numerous works established there. On his proposition were opened, in the Donetz Basin, South-Eastern Russia, the earliest collieries in the empire. At General Tscheffkine's recommendation, and under his direction, the first general geological survey of Russia was executed. In this work, a prominent part was borne by the late Sir Roderick Murchison, who was invited by Tscheffkine to share in the labours of the survey, and an intimate friendship subsisted between the two until Murchison's death. The St. Petersburg Institute of Mining Engineers, a government establishment, was largely indebted to the patronage of General Tscheffkine for the position it attained of one of the first mining schools in Europe, with a museum said to be the richest of its kind in the world. As a member of a special committee for the construction of railways, Tscheffkine rendered great service to the cause of material

Digitized by Google

progress, and was one of the most active and staunch supporters of the St. Petersburg-Moscow railway (the first in Russia), when its construction was decided upon against a fierce opposition of powerful interests. On the accession of the present Emperor Alexander, a wider field was opened up for Tscheffkine's activity. In 1856 he was appointed Minister of Public Works, Member of the State Council, and of the numerous special committees which were created for the study and elaboration of those reforms, the carrying out of which have made the reign of the present Emperor the most glorious epoch of Russian history. The emancipation of serfs and their endowment with landed property were much helped by the energy of Tscheffkine. As Minister of Public Works he organised the first railway companies in Russia, five being formed during his administration, viz., the Grand Russian Company, which constructed the St. Petersburg-Warsaw and the Moscow-Nijni-Novgorod, aggregating 1,500 miles; the Riga-Dunaburg, the Moscow-Riazan, the Moscow-Jaroslav, and the Volga-Don companies, first instalments of the network of 18,000 miles of railways now working in European Russia. The telegraph lines intersecting Russia in every direction from China to the Baltic were also originated, and in great part erected, during the time General Tscheffkine held the Ministry of Public Works. In 1862 illness obliged him to resign, and he spent the subsequent two years abroad, visiting Switzerland, Italy and France in the endeavour to recruit his health, almost broken down by overwork. Feeling somewhat stronger, he in 1864 returned to Russia, and again took an active part in the administration of the country, especially in elaborating the scheme for provincial elected government boards, in the judicature reform, in the introduction of juries into criminal courts, and in public instruction. As president of the department of economy in the State Council, he took a prominent part in the reorganisation of Russian finance, and to his enlightened and energetic endeavours, with the co-operation of the present Minister of Finance, Reutern, and the late Controller-General Tutarinoff, Russia is indebted for having passed from an era of yearly deficits to a condition enabling her to balance revenue and expenditure, so that since 1866 no state loans have been contracted.

In a career of such exceptional activity General Tscheffkine necessarily ran counter to many interests, and although he had numerous and warm admirers, he could not but have also many enemies; but not even his foes ever disputed his absolute integrity, patriotism, and sincerity. He was accused of occupying himself too

Digitized by Google

much with detail, and of being too exacting towards those placed under him; but those who knew and worked with him will acknowledge, that he never exacted from others as much as from himself, and his entire devotion to his work made him consider every detail important. The compiler of this notice having been for three years aide-de-camp to General Tscheffkine while Minister of Public Works, has personal experience of his kindness and regard towards those who were placed under him, and cannot refrain from paying his tribute of admiration and affection to the memory of his late chief, of whose friendship he was and will always be proud.

General Tscheffkine was elected an Honorary Member of the Institution of Civil Engineers on the 24th of May, 1859. He died at Nice, on the 18th of November, 1875.

Mr. THOMAS HARDINGE GOING, B.A., third son of the late Mr. William Going, of Altavilla, Cahir, county Tipperary, was born on the 8th of August, 1827. He entered Trinity College, Dublin, in the year 1845, and after passing through the University in a highly creditable manner, obtaining the diploma of the Engineering School attached to the College, he left in 1850, and was employed at home for about two years. After that he went to the United States, and was engaged on the Lebanon Valley and the Reading and Lehigh Valley railroads, chiefly for Mr. Richard Osborne, of Philadelphia. He returned home in 1857 with the intention of seeking employment in India, and obtained an appointment as an Assistant Engineer on the staff of the Madras Railway Company. He remained in India in the service of that company for eighteen years, ultimately arriving at the post of Assistant Chief Engineer, with the immediate prospect of being appointed Chief Engineer. He died of abscess on the liver, on the 15th of September, 1875, at the residence of his brother-in-law, Mr. Alexander D. Kennedy, The Grove, Killiney, co. Dublin.

Mr. Going was elected a Member of the Institution of Civil Engineers on the 5th of December, 1865; but his continuous residence in India prevented his taking any part in the proceedings.

Mr. JAMES STIRLING, born at Methven, in Perthshire, on the 20th of July, 1800, was descended from a highly respectable farmer family, nearly every member of which, females included, possessed mechanical talent almost amounting to genius. He originally

Digitized by Google

studied for the Church at Glasgow and at Edinburgh, but early directed his attention to mechanical engineering. He served an apprenticeship with Messrs. Claude Girdwood and Co., of Glasgow; and was subsequently engaged for some years as engineer at the Deanston works, when that well-known establishment was conducted by the late Mr. James Smith, and materially assisted in the construction of the famous salmon-ladder on the river Teith. He afterwards became Engineer, and latterly Manager, of the Dundee Foundry, where he constructed for the Swedish Government a steamer which he took out and delivered, being kindly received by the Royal Family. Mr. Stirling was much occupied in the improvement and practical working of the air-engine, a description of which he contributed to the Institution in 1845.[1] The same principle was subsequently adopted by Mr. Ericsson, whose name is generally connected with the invention. The merit of the original idea belongs to Mr. Stirling's elder brother, Dr. Stirling, the venerable minister of Galston, Ayrshire; but it was by Mr. James Stirling's persevering ingenuity that it was so far perfected that the engine worked well, and proved an economical mode of producing power at the Dundee Foundry, and also at a spinning-mill in the same town. The engine was, however, ultimately laid aside in consequence of its being found impossible to preserve the air-heating vessel from being melted or burnt, which both Mr. Ericsson and the late Professor Rankine, of Glasgow, who experimented in the same direction, found an equally insuperable difficulty. In this connection Dr. Stirling writes, under date Galston, 19th of January, 1876:—

"... It surely cannot be unreasonable, nay it is a duty in taking notice of the death of James Stirling, to make a remark which may stimulate the spirit of invention, or even contribute to realise its ambitious hopes. It is a fact, then, that he almost succeeded in establishing a new mechanical power, which promised to relieve the labours of that gigantic and universal drudge the steam-engine. He constructed at the Dundee Foundry an air-engine which for three years performed all the work of that establishment, and failed at last from imperfections in the material of which it was constructed. These imperfections have been in a great measure removed by time, and especially by the genius of the distinguished Bessemer. If Bessemer iron or steel had been known thirty-five or forty years ago, there is scarce a doubt that

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iv., p. 348.

Digitized by Google

the air-engine would have been a great success. But as the nature of cast iron forty years since required the hot part of the engine to be made three times thicker than it would now be, and consequently at least six times less fit for transmitting the heat, the outside of it required to be kept at a much higher temperature than would have been necessary with Bessemer iron. The hot part also was made convex, and required to be protected by a screen of bricks, the destruction of which by neglect implied the destruction of the engine; on the contrary, if the vessel had been concave and allowed to get a sight of the fire, as would now be easily accomplished, its operation would have been much more efficient, and the vessel, being equally heated, would not have been liable to crack.

"The engine, such as it was, worked to the extent of 40 HP., according to the standard of Watt and Boulton; and this was ascertained not by theoretical calculations, but by the proper application of the Trutsen strap and movable weights frequently used. Upon the whole, this experiment was conducted with such care and skill, and such jealousy of being deceived, that the result as to power, &c., may be considered as fully established. It remains for some skilled and ambitious mechanist in a future age to repeat it under more favourable circumstances and with complete success."

While at Dundee Mr. Stirling made the ornamental cast-iron dome, tank, engine, and pump, and a ball and socket pipe across the Tay for the Perth Waterworks; the iron ribbed gates of Earl Grey's Dock, Dundee, 55 feet in width, dimensions at that time (1834) considered large; in 1841, gates for Montrose Dock similar to the former, except that they were covered on both sides with iron boiler plates, which, it is believed, was the earliest application of iron to that purpose. As early as 1833 Mr. Stirling made several locomotive engines for the Dundee and Newtyle, the Cupar Angus, and the Arbroath and Forfar railways, and was proud of having run one of his engines up the Balbuchlay incline of the Dundee and Newtyle line, a gradient of 1 in 25. He exhibited considerable ingenuity and originality in designing and adapting a reversing gear for the locomotive, which acted well, but has since been superseded by the more modern link motion.

In 1846 Mr. Stirling left Dundee to settle in Edinburgh, where he afterwards resided, fulfilling various professional engagements, among them the construction of a large gauge weir on the river Leny for the Glasgow Water Company, preparing the working

Digitized by Google

plans of the Blackhill incline plane, for taking up boats afloat in the Monkland canal, Glasgow, and in superintending that work. He was for a time much engaged in arbitrations and in the valuation of machinery, and was accounted a high authority in all matters relating to mill wheels and water power. He invented a water meter, which indicated correctly and worked well, but not under pressure, a serious drawback to its general adaptability. It was, however, theoretically and practically an exact and actual measurer, and not a mere indicator, liable to have its results affected by varying rates of flow, and it was particularly well adapted for measuring the water delivered into cisterns. He took no patent or other protection for the meter, and received no pecuniary benefit from its sale.

In Edinburgh Mr. Stirling led a life of quiet citizenship. Enhanced by his own eminently kindly and hospitable disposition, the literary gifts and connections of his wife (he married in 1857) rendered his house in Hill Street for nearly a quarter of a century a centre of intellectual sociality. He died on the 10th of January, 1876, aged seventy-five years.

Mr. Stirling was for nearly forty-two years a Member of the Institution of Civil Engineers, having been elected on the 10th of June, 1834.

Mr. AUGUSTUS BEATTIE BRADBURY, second son of Mr. Charles Bradbury, was born on the 1st of August, 1841, at Hobart Town, Tasmania, where his father held an appointment as one of Her Majesty's Inspectors of Schools. He was educated at the "Hutchins School," and served a regular pupilage under Mr. Thomas Alcock Tully, Inspecting Surveyor to the Government of Tasmania, who, among other duties, at this time conducted an important exploring expedition on behalf of the Government, so that his pupil enjoyed considerable advantages. At the expiry of his articles Mr. Bradbury selected India as his future field of work, and entered the service of the Madras Irrigation and Canal Company in 1863. He was appointed Assistant Engineer in 1864, and for two years had responsible charge of the surveys of the Massoor reservoir, of 30 miles area, and also assisted in getting up the plans and estimates of the Upper Bellary Canal Scheme. In August 1867 he was put in charge of a range of 10 miles of canal including an aqueduct, culvert, &c., then under construction, which was successfully opened in 1868. By ability and steadiness of purpose he rose in position as vacancies occurred, carrying on important

Digitized by Google

works with energy and success. The strain upon body and mind, together with the trying climate, must have been long telling on a robust constitution; and though due for furlough at the expiration of seven years' service, Mr. Bradbury remained at his post, his services being needed by the company. At length, in 1874, he returned to England; but the relaxation came too late, and he succumbed to the repeated returns of Indian fever, dying in London on the 7th of November, 1875. Mr. Bradbury was elected an Associate of the Institution of Civil Engineers on the 7th of December, 1869.

Mr. SEYMOUR CLARKE, the second son of Mr. Frederic Clarke, was born at Streatham, Surrey, in the year 1814. About the year 1834 he was introduced to the late Mr. Isambard K. Brunel, Vice-President Inst. C.E., in whose office he commenced his engineering studies, and whom he assisted in the preparation of the designs for the Monkwearmouth Docks, the Clifton and the Hungerford Suspension Bridges, and more particularly the Great Western railway, and its various branches, all the details of the surveys, calculations, &c., passing through Mr. Clarke's hands.

When the Great Western Railway Company were about to arrange the staff preparatory to the first opening between Paddington and Maidenhead, Mr. Brunel introduced Mr. Clarke, of whose judgment and abilities he had conceived the highest opinion, to the notice of the Board, as being in his view the most suitable person for the appointment of Superintendent of the London division of the railway. This led to Mr. Clarke's engagement in October, 1837, when he was directed to proceed to the north of England and to Belgium to study the systems there established for the working of railways. He was also instructed, in conjunction with the late Mr. C. A. Saunders, to organise the whole of the establishment requisite for the service, the preparation of the necessary carriage and wagon stock, and all the details appertaining to the traffic department.

Shortly after this the well-known question as to the gauge was mooted, and during the long and important investigations by Messrs. R. Stephenson, N. Wood, and Hawkshaw, MM. Inst. C.E., at the instance of the Directors of the Company, Mr. Brunel was assisted by Mr. Clarke, together with the late Mr. C. A. Saunders, and Mr. (now Sir Daniel) Gooch, in conducting the experiments in proof of the soundness of the theory as to the broad-gauge system,

Digitized by Google

in opposition to the views expressed against it. He also gave evidence before the Royal Commission appointed by Parliament on this important subject in 1846. With the gradual extension of the Great Western Mr. Clarke was intimately connected, and he was, in 1840, placed in charge of the line from London to Swindon.

In May, 1850, Mr. Clarke became the General Manager of the Great Northern railway, when he resigned the post he had so long held with credit to himself and to the advantage of the Great Western Company. His admirable administrative abilities, his coolness of judgment in the most trying circumstances, had gained for him the respect and esteem of the Directors as well as of a numerous staff. On leaving the Great Western his late colleagues, with a large number of the staff, evinced their personal regard and appreciation of his merits by the presentation of a handsome testimonial, consisting of a portrait of Mrs. Clarke and her family, with a complete breakfast service of silver plate.

The extension of the Great Northern line from London to Peterborough took place shortly after his appointment, when he was enabled to commence his efforts in developing the traffic of that important system. The success of his policy was soon felt by the Great Northern proprietors in the altered position of the undertaking, which rapidly assumed a first rank in competition for the traffic of the Northern and Midland counties and Scotland, together with the establishment of the large and important traffic between London and the northern and southern Yorkshire coalfields. Notably he was instrumental in devising and carrying through the Gladstone Award, or "ten towns agreement," for the division of the traffic between the Great Northern of the one part, and the London and North-Western, Midland, and Sheffield railways of the other part. In framing the various treaties and agreements with other companies, the discretion and far-seeing policy of Mr. Clarke soon became evident. His singular accuracy of mind and clearness of statements, which have stood the test of experience, placed him second to none in these negotiations. His knowledge of all railway details and his high sense of honour, candour, and straightforward fixity of purpose gave weight to his opinions; and the evidence he was constantly called upon to give before Committees of both Houses of Parliament, both on behalf of the Great Northern as well as of other companies, commanded and insured attention.

These qualities, and his indefatigable perseverance in all business transactions, led to Mr. Clarke's selection by the ministry of the time (1867) as one of the Royal Commissioners appointed

Digitized by Google

to inquire into the position, prospects, and value of the Irish railways; to examine into their various incomes and expenditure, assets and liabilities, &c.; the state of repair of all the lines; and the value, &c., of the rolling stock. In this commission Mr. Clarke was associated with Sir A. Spearman, Messrs. J. Mulholland, John Fowler, and C. Johnstone. Their report was mainly his work, in connection with Mr. Fowler, Mr. Clarke having made a personal inspection of the whole of the Irish railways.

His constant and arduous attention to these various duties proved so great a strain on his constitution that, after twenty years' unremitting hard service, he was compelled, in September 1870, through a most severe illness, to resign the appointment he held in the Great Northern Company, and to retire into private life. On this taking place Mr. Clarke received from the railway managers and engineers of the kingdom a handsome testimonial, together with another presented by the officers and employés of the Great Northern Company. At the same time came another most valued expression of goodwill from the principal gentlemen officially connected with the Indian railways; nearly all of whom had either been in the service of the Great Northern Company, under Mr. Clarke, or had been well known to him during their career in this country. These several recognitions were received by Mr. Clarke with unalloyed satisfaction, and tended not a little to alleviate the sorrow and disappointment he sustained at being thus early compelled to abandon his professional career.

Enforced quiet conduced to a partial re-establishment of health, and in 1874, when the change took place in the direction of the Great Western railway of Canada, Mr. Clarke was induced, by those connected with the company who knew of his great experience in railway affairs, to accept the office of Vice-President of that undertaking. He was also the Deputy Chairman of the Banbury and Cheltenham railway. These offices he held up to the time of his decease, which occurred, after a few weeks' illness, at Walthamstow, on the 15th of March, 1876.

Mr. Clarke was elected an Associate of the Institution of Civil Engineers on the 5th of December, 1865, and on the creation of the Engineer and Railway Volunteer Staff Corps in the same year he received Her Majesty's commission as a lieutenant-colonel in that corps.

Mr. GEORGE CÆSAR COOKE was the son of the Rev. John Cooke, rector of Ardfinan, diocese of Lismore, Ireland. In order to acquire a technical education he entered the Engineering School

Digitized by Google

of Queen's College, Cork, in October, 1856, obtaining an exhibition at entrance. Having completed his course in the college, he served for a year under the late Mr. W. Dargan, the well-known contractor, on the Tuam and Athenry railway, and afterwards under Mr. J. Bowen, M. Inst. C.E., in getting up parliamentary plans and sections for the Finn Valley and Letterkenny railways. At the competitive examination for appointments in the Public Works Department of India, held in June, 1861, Mr. Cooke obtained the fourth place, and proceeded to India as an assistant engineer in that service, and was promoted to executive engineer in September, 1868. He was first employed in preparing plans and estimates for the Patna branch railway in Bengal, and afterwards on the construction of a portion of the same road. In 1864–5 he had charge at Mhow of the erection of several important buildings, including a new European Infantry Hospital, which he completed, and also of the Simrole Ghâts on the Mhow and Khundwa Road, a great portion of which he constructed, and for which he prepared a revised estimate. In February, 1867, Mr. Cooke was appointed officiating Executive Engineer of the third division of the Mhow and Nusseerabad Road, afterwards known as the Ajmere Roads Division, which embraced several roads in Ajmere and the adjoining native states, as well as the civil buildings in the district. For several years previous to his death he had charge of the Sagar Road Division, including the construction of 72 miles of road, and the care of the new civil buildings in Sagar and Nursingpoor.

Mr. Cooke was elected an Associate of the Institution of Civil Engineers on the 2nd of December, 1873, and shortly afterwards presented a Paper on "Practical Methods of determining the Waterway to be provided in crossing the Drainage on Long Slopes leading to Indian Rivers." He died of small-pox in 1875.

Mr. JESSE HILDRED, born on the 6th of June, 1843, at Carlton, in Lincolnshire, was apprenticed at an early age to a builder, but the routine proving uncongenial, he started afresh on a new career. By close application to study, and indomitable perseverance, he succeeded in qualifying himself for the post of Surveyor to the Thornhill Local Board, Dewsbury, to which he was appointed in 1865. His duties were unusually varied and responsible; his success, however, was eminently satisfactory. In 1869 he was selected as Surveyor to the borough of Batley, where his abilities soon won for him the full confidence of the

Digitized by Google

municipal authorities. In 1873 he made a survey of the borough, and prepared a scheme for its sewerage, including purification works, for street improvements, for a public marketplace, and for small-pox and fever-hospitals, all of which were approved by the Local Government Board, and were commenced under his supervision. In 1875 he obtained the appointment of Surveyor to the borough of Blackburn, Lancashire; but shortly after entering upon the duties of that office he was seized with a painful illness, which in a few hours closed his brief but useful life. Mr. Hildred was a man of unflagging energy, and ardently devoted to the profession. His sewer and drain ventilators, and ventilator for house-drain traps, are among the many proofs of his practical ingenuity. His powers of mind were of no mean order; and not less remarkable was an amiability of manner which endeared him to many friends, and secured the confidence and respect of those with whom he was connected.

Mr. Hildred died on the 20th of November, 1875, at the age of thirty-two, having only been elected an Associate of the Institution of Civil Engineers on the 2nd of March in the same year.

Mr. EVAN LEIGH, son of the late Mr. Peter Leigh, an extensive cotton-spinner, at Ashton-under-Lyne, was born on the 21st of December, 1810. The intricate surroundings of a cotton-mill appear to have been congenial to his natural proclivities; for when a youth of about twenty, young Leigh effected an improvement in the mule, which almost revolutionised the trade, reducing the cost of spinning on the mule from 5*d.* to about 3*d.* per lb. This he accomplished by the coupling of mules and the 'putting-up motion,' an invention that was not patented and soon became common property. Mr. Leigh was at this time in partnership with his father, and continued in the cotton trade for about twenty-five years. In the interval he took out many patents for improvements in machinery, especially cotton-spinning. In 1850 appeared the first of a series relating to carding engines, also slubbing and roving frames, paper tubes, throstles, and the use of cast iron for spindles. The invention with which Mr. Leigh's name is principally associated is, however, the self-stripping carding engine, of which he claimed to be the originator. In working out this idea he at first employed an endless cloth of flats and then an endless chain, and made or altered about a hundred machines to the new system. But it was found to be defective, and resulted in a

Digitized by Google

heavy pecuniary loss, as the defects sometimes caused considerable damage to the card clothing from the flats going the wrong side up. This was successfully overcome by the adoption of a bushed chain, which prevented the complete turning over of the flats. The machines then found favour, and soon brought competitors into the field. In 1858 he patented a further development of the machine, part of which formed a new grinding arrangement without removing the flats. Mr. Leigh's interest in the carding machine continued to the last, for in 1875 he took out, in conjunction with his son Mr. E. A. Leigh, another patent, which they were engaged in perfecting at the time of his death. The business soon outgrew the premises at Collyhurst Mill, and during the American war he erected and started the fine works at Miles Platting, where he carried on the business of machine manufacturing, under the firm of Evan Leigh and Son, until the year 1864, when the works became the property of a limited liability company, though they still bear his name.

In 1849 Mr. Leigh patented the twin screw, of which he was the original inventor, although the principle did not come into use until after the expiry of his patent. Then the principle was adopted in a vessel that was being fitted out by Messrs. Dudgeon, of London, for the China trade, but on account of her handiness was sold by the builders to a Whitby firm, who employed it as a blockade-runner during the American war. In connection with this subject, the following note is extracted from one of many papers and pamphlets, relating to mechanical works, which Mr. Leigh from time to time put forth:—

"In the year 1849, I took out a patent (No. 12,708, dated July 18th) for steering ships, by having separate power to each propeller, being twin screws or detached paddles, with the object of turning a vessel more readily out of its course in time of danger, by reversing one paddle or other propeller, and steering generally by giving more or less steam to one engine or pair of engines. Notwithstanding the common sense of this arrangement, by which all the power on board could be employed in cases of emergency to avoid collisions, &c., I could neither get the Government of the day nor any of the shipbuilders to take it up; but I must admit that I received a letter from the Lords of the Admiralty thanking me for the communication, but nothing more."

Another subject in which Mr. Leigh took a deep interest was a project for transporting railway trains on shipboard. In 1870 he published a pamphlet, with a large diagram, entitled "A Plan for conveying Railway Trains across the Straits of Dover." Some

Digitized by Google

years afterwards he exhibited, at a conversazione of the Manchester Scientific and Mechanical Society, a model of this design, and gave explanations of it in the presence of many representatives of science and engineering.

In 1871 Mr. Leigh published a work giving the results of nearly half a century of practical experience of mills and mill machinery. It was issued in two large volumes, with numerous illustrations, under the following explanatory title: "The Science of Modern Cotton Spinning, embracing Mill Architecture, Machinery for Cotton Ginning, Opening, Scutching, Preparing, and Spinning, with all the latest improvements; also articles on Steam and Water Power, Shafting, Gearing and American system of Belting compared, Generation and Application of Steam criticised and explained, Boilers, Boiler Explosions, &c., all tending to show where the outlay of capital may be economised, and production cheapened."[1] This work is one of authority, circulating both in Europe and in America, and in 1875 had attained its third edition.

At the time of his death Mr. Leigh was in practice as a consulting engineer; he was also interested in the firm of E. A. Leigh and Co., machinery contractors and shippers, Manchester; Evan Leigh and Son, merchants and shippers, Liverpool; and F. A. Leigh and Co., importers of machinery, Boston, U.S. In 1863 he was elected a Member of the Institution of Mechanical Engineers, and he has taken an active part on its Manchester committee. On the 3rd of December, 1872, he was elected an Associate of the Institution of Civil Engineers. He was also an Associate of the Institution of Naval Architects, a Member of the Society of Arts, and in May 1875 he was elected President of the Manchester Scientific and Mechanical Society, of which latter society he was one of the founders in 1870.

Mr. Leigh had latterly become subject to chronic bronchitis, and this, aggravated by heart-disease, caused his death on the 2nd of February, 1876, in his sixty-sixth year. His loss is widely regretted, not only as a man of science, but for the unostentatious way in which he engaged in works of charity.

MR. WILLIAM CHADWELL MYLNE, the second son of the late Mr. W. C. Mylne, M. Inst. C.E., F.R.S., was born at the New River Head, Clerkenwell, on the 7th of February, 1821. He

[1] This work was presented to the Institution by Mr. Leigh, and may be consulted in the Library.—SEC. INST. C.E.

Digitized by Google

entered his father's office at an early age, and in November 1845 was appointed River Surveyor in connection with his father, the Engineer-in-Chief to the New River Company, who had himself succeeded, in 1811, Robert Mylne, the grandfather of the subject of the present notice. Mr. Mylne, for three years previous to his appointment, was an assistant in the New River Company's works, and he continued the duties of River Surveyor until the spring of 1875, when, from ill-health, he resigned this office and retired to Bath. Mr. Mylne's professional occupations were almost wholly confined to the service of the New River Company, whose extensive concerns necessarily absorbed almost his entire attention. At various times, however, he was engaged in other undertakings, and his last independent professional work was the successful construction, in 1869, of a deep shaft into the chalk at Coldbath Fields House of Correction, Clerkenwell, for a supply of water to that establishment.

Mr. W. C. Mylne was elected an Associate of the Institution of Civil Engineers on the 13th of April, 1847, and he died at Bath on the 14th of March, 1876, aged fifty-five.

Mr. FRANCIS NAPIER, the second son of Mr. David Napier of Glenshellish, Argyleshire, and of Millwall, London, whose connection with the early history of steam navigation is well known, was born at Glasgow in the year 1820. He was educated at the Grammar School and University of that city, and studied marine engineering in the workshops of Messrs. Tod and Macgregor, on the Clyde. He was the inventor of the four-piston-rod engine still often met with on that river and elsewhere, and of which the first was fitted in 1842 on board the London, Ramsgate, and Dover steamer, "Isle of Thanet." In 1852 Mr. Napier went to Sydney, New South Wales, and was for some time manager of the Australasian Steam Navigation Company. Afterwards he was in business there on his own account for some years. Being more inclined for scientific pursuits than for practical engineering, he joined the expedition under Captain Cadell, equipped in 1867 by the South Australian Government for the purpose of exploring and surveying their northern territory. On this expedition he discovered a channel, now known as Cadell Strait, between Elcho Island and the mainland, the peninsula there bearing his own name. "An Account of the Natural History and Physical Geography" of this voyage, which he was preparing when he died, was recently communicated by one of his cousins to the Philosophical Society of Glasgow; also a note, "On the apparent

Digitized by Google

Absence of Air and Water from the Moon," both of which are printed in the Proceedings of that society. Mr. Napier returned to Glasgow in 1871, and there joined his brothers in their engineering business. He died, after a short illness, at his sister's house on the Gareloch, on the 23rd of December, 1875.

Mr. Napier was elected an Associate of the Institution of Civil Engineers on the 9th of January, 1866.

MR. PHILIP ALGERNON HERBERT NOYES, seventh and youngest son of Mr. Thomas Herbert Noyes, of East Mascalls, Lindfield, Sussex, was born at St. Germain-en-Laye, France, on the 21st of August, 1843. His education, begun at a school in Brighton, was continued at King's College, London, which he entered in 1860, with the intention of studying for the Indian Civil Service. Eventually however he decided to become a civil engineer, and in June 1863 he was articled to a mechanical engineer at Birmingham; in January 1865 he became a pupil of Mr. Hemans, M. Inst. C.E., with whom he remained till January 1868, being employed during part of that time in the construction of railways in the north-west of Ireland. He afterwards continued to work for a short time in the same office, and then joined a mechanical engineering firm which carried on business at Northfleet under the style of Alibon and Noyes. Subsequently, in August 1871, he was appointed by the Ceylon Government an assistant engineer on the railways in that island. He worked at first under Mr. John Rhames Home, on whose removal to another post, in March 1875, Mr. Noyes was requested to take up the duties of engineer in charge. In the summer of 1875 he was employed at Colombo, where his work led him for the most part through the cholera-stricken districts of that town, and the constant exposure to sun and wet in such a trying season and climate caused his health to fail, and the first symptoms of the fatal disease (progressive locomotor-ataxy) to which he afterwards succumbed, became apparent. He was recommended by his medical adviser to return to England at once, but was unwilling to give up his duties until convinced that all hope of being able to resume them was at an end. He therefore postponed his departure till October, when he embarked in the steamship "Sirius," which reached Gravesend on the 7th of November. He grew steadily worse during the voyage, died in London on the 15th of November, 1875, and was buried at Great Gaddesden, in the county of Herts.

Digitized by Google

Mr. Noyes was one of the original members of the Student class of the Institution of Civil Engineers, having been admitted on the 19th of November, 1867. In due time, on the 1st of February, 1870, he was elected into the Corporation as an Associate, and his early death cut short a career of much promise.

Mr. JAMES ROBERTSON, the second son of Mr. James Robertson, land-steward on the estate of Sir Patrick Murray Threipland, Bart., Fingask Castle, Errol, N.B., was born at Stronchavie, parish of Moulin, Perthshire, N.B., on the 26th of December, 1835. He was educated first at Moulin Parish School, afterwards at Kinnaird Parish School, and finally at Kinnoull Street Academy, Perth. On the 17th of April, 1854, he entered as an apprentice the office of the late Mr. Thomas Telford Mitchell, Assoc. Inst. C.E. During this pupilage he superintended the construction of the short railway from Perth to Methven, the branch line from Cupar-Angus to Blairgowrie, and the branch from Larbert to Denny; also the Dunblane, Doune, and Callander railway. Afterwards he was for a considerable time employed on the survey for the proposed supply of water to Glasgow from Loch Katrine. In the beginning of 1858 Mr. Mitchell took the contract for the construction of the Castle Douglas section of the Portpatrick railway, of which Mr. Robertson had the entire charge till about the end of 1860, when he accepted an appointment in India with Messrs. Lee, Watson, and Aiton, who held the contract for the construction of the Nagpore Extension of the Great Indian Peninsula railway. Here Mr. Robertson for several years had charge of districts, giving great satisfaction to his employers, as well as to the railway company, and proved himself peculiarly competent to carry out public works in India and to manage natives. When the contractors returned home he was left in full charge of the completion of their undertaking, about 280 miles. For valuable assistance during the Nagpore Exhibition of 1865, in forwarding goods by the contractors' train, and generally giving advice in the furtherance of this object, he received the thanks of the Government of the Central Provinces.

In June, 1868, he returned to this country to recruit his health, and in the autumn was asked to go to India again, to take charge for the contractor, Mr. Joseph Bray, of No. 19 contract on the same railway, from Goolburga to Raichore, which was also completed to his employer's satisfaction. Mr. Robertson finally returned to this country at the end of 1870, and shortly afterwards

Digitized by Google

entered into partnership with a firm of iron manufacturers in Scotland. But his arduous duties in India, combined with the effects of a trying climate, had so impaired his health that he never afterwards quite recovered his strength, and he died in Glasgow on the 5th of April, 1876.

He was elected an Associate of the Institution of Civil Engineers on the 3rd of December, 1872.

MR. PETER THOMSON,[1] born about the year 1815, was the architect of his own fortunes, for, beginning with very little, he in time reached a position of affluence and public importance. He was a native of the village of Forgue, near Huntley, Aberdeenshire, where his father, who had a numerous family, was a builder in a small way. The boy served his time as a mason to his parent, and subsequently attended a drawing class in Aberdeen, becoming proficient as a draughtsman. At the age of twenty-two he joined his elder brother George, who had then gained considerable reputation as a railway contractor, near Halifax, Yorkshire, and in the course of a few years developed such aptitude for the business that he was taken in as a partner. He also joined the firm of Rennie, Logan, and Co., of Newport, Monmouthshire, which worked in conjunction with the other undertaking for some time afterwards, the operations of the Newport firm extending over the southern districts of the country, whilst those of George Thomson and Co. were more directed to works in the midland and northern portions of England. A couple of years having elapsed, he went to Liverpool to superintend the construction of the first Kensington reservoir. He next repaired to Heywood, near Rochdale, where he remained for three years, and had charge of the construction of a portion of what is at the present time the main line between Bolton and Rochdale; the extension of a branch railway through the town of Oldham; the making of part of the line from Shipley to Bingley, and the construction of a portion of the Midland railway through Darley Dale to Rowsley and Bakewell. He also made the railway from Matlock to Buxton, where in order to avoid the destruction of the picturesque seat of Haddon Hall, a tunnel is carried beneath the mansion. In 1849 he returned to Liverpool, where his permanent residence was fixed, and where the head-quarters of his firm

[1] The substance of this notice is taken from the "Liverpool Courier" of May 15, 1876.

Digitized by Google

became located. Among the numerous local works which he undertook and carried out were the extension of the old Liverpool and Bury railway from Chadwick Street to Tithebarn Street and the building of the Exchange Station, and the construction of the line between Sandhills Junction and Waterloo (the Liverpool, Crosby, and Southport railway). He built the North Dock branch railway from Sandhills to the Stanley Dock, and deepened the Great Float for the Mersey Docks and Harbour Board. This work gave employment for three years to about 46,000 men and 240 horses, and from 2 million to 3 million cubic yards of excavations were made, the material furnishing the means of raising about 160 acres of Bidston Marsh. He likewise constructed the Carriers' Docks and the Canada Half-tide Dock; the London and North-Western branch to Canada Dock, including the tunnel under the Liverpool and Leeds Canal, a difficult undertaking, as it involved the temporary diversion of the canal without stopping its traffic; the expansion of the tunnel to Wapping Station and the station; and the Prescot reservoir for the Rivington water supply. The new reservoir at Kensington was also made by him, and the old one covered in. The other undertakings in which he took a prominent part consisted of the execution of the Mountry House and Aspull Moor intermediate reservoirs between Liverpool and Rivington; the "short line" from Bradford to Leeds; extensive railway works in the town of Leeds for the London and North-Western, the Leeds and Dewsbury, and the Midland Companies; the Midland railway between Whittaker and Nuneaton; the Newport, Abergavenny, and Hereford line, 32 miles in length; a portion of the South Wales railway between Newport and Swansea; the railway across the bay at Fleetwood; the Newport docks; a portion of the Penarth docks, Cardiff, with a line to the mineral districts; the Edgehill and Bootle branch of the London and North-Western railway; the Canada Dock Station, and the extensive warehouses there; the Aintree and Bootle branch of the Lancashire and Yorkshire railway from Fazakerley to the North Mersey Station in Regent Road; the Brunswick Station at the south end for the Cheshire Lines Committee; the completion of the Edgehill and Garston line; the railway between Huyton and St. Helens, through Prescot; the greater part of the new line from Sheffield to Chesterfield; the erection of the Leeds new station, a work which was commenced in 1867; and the building of a railway upon arches through that town for the North-Eastern Company.

Mr. Thomson became joint proprietor with his brother of the extensive ironworks at Normanton, now under the control of a

Digitized by Google

limited liability company. Some of his last works were the erection of the new station, grain warehouses, and other building operations in Wakefield; the new stations in Halifax and Bradford, and the widening of the Barnsley branch railway into a double line for the Lancashire and Yorkshire Company. Mr. George Thomson died at Cheltenham in 1867, and after that event the responsibility cast upon the shoulders of the younger brother was of a still more onerous nature. The great practical knowledge he possessed was widely recognised, and he was frequently consulted on difficult points by some of the most eminent engineers. On becoming a director of the Lancashire and Yorkshire Railway Company he retired from business. Though having ceased participation in the undertaking, he retained an office at the Bankhall Works, and regularly visited it up to the time of his fatal illness.

Mr. Thomson joined the Volunteers at the commencement of the movement. In 1860 he was a captain in the 2nd Administrative Brigade, composed of the 12th and 17th Lancashire Artillery Volunteers; he was afterwards promoted to the rank of major, and on the 25th of May, 1861, he received his commission as lieutenant-colonel commandant of the battalion. He became a candidate for the representation of St. Paul's Ward in March 1871, but was defeated by a small majority. The Council, however, loth to lose such a valuable man, elected him an alderman on the 19th of the following month. He proved himself a most useful member of the Corporation, as chairman of the Works Committee of the Water Committee, while the aid which he gave in the investigations of the Special Committee with reference to a new water supply was equally advantageous to the Corporation. He was also for some time on the Health Committee. As a fitting reward for his unremitting labours on behalf of the town he was elected to the office of chief magistrate of Liverpool by the unanimous voice of the Council on the 9th of November, 1875. He died on the 13th of May, 1876, shortly after a visit to London at the head of a deputation for the purpose of inviting the Royal Agricultural Society to hold their next Show at Liverpool.

Mr. Thomson was elected an Associate of the Institution of Civil Engineers on the 2nd of April, 1867. He was besides connected with other scientific and public bodies, and was a J.P. for the county of Lancashire.

Digitized by Google

SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Experiments on Cements at Bangalore.

By SURGEON E. NICHOLSON, B.M.S.

(Roorkee Professional Papers on Indian Engineering, 2nd Series, vol. iv., pp. 61 & 376.)

On the Adhesion of Mortars to Brick and Stone.—The bricks, although of excellent quality, were often unable to bear a strain sufficient to rupture the mortar. Thus with 17 to 22 lbs. per square inch at the moment of rupture the bricks showed a tendency to peel. Above this point they were liable to break off outside the joints, while with 28 to 30 lbs. per square inch a piece would sometimes be torn out of one brick, the joint remaining intact. Being unable to ascertain the maximum strength of the mortar, owing to the failure of the bricks, blocks of burnt stone (gneiss) of Bangalore were cut to the same size, and with these it was possible to test the adhesive strength of the best cement. In the course of the experiments, it was found that the adhesive strength to stone was invariably greater than to bricks, in the proportion, on the average, of 1·7 to 1.

On the best way of using Mortars of Sand and Fat Lime.

ADHESIVE STRENGTH of JOINTS MADE with MORTAR of 1 SHELL LIME PASTE, 2 SAND.

	Breaking Weight.	Square Inch.
	lbs.	lbs.
A. Bricks dry, mortar rather stiff	39	2·1
B. „ „ thin	57	3·1
C. „ „ „ bricks dashed with water	67	3·7
D. Bricks soaked 10 seconds, mortar rather stiff	82	4·5
E. „ „ 2 hours „ „	56	3·1
F. „ „ 2 hours, drained 1 hour, mortar rather stiff	67	3·7
G. Stones wetted	136	7·2

Thus it is seen that the best results were obtained when the bricks were soaked for a few seconds only.

Digitized by Google

On the best Proportions for Mortars of Fat Lime and Soorkee [pounded brick] to be used in Masonry and Brickwork.

Composition of Cement.	Adhesive Strength.	Tensile Strength.
	lbs. per Sq. Inch.	lbs. per Sq. Inch.
1 lime paste, 1½ Soorkee.	20·5	62
1 „ 2 „	11·1	91
1 „ 3 „	17 to 27	95
1 „ 4 „	10·0	114
1 „ 5 „	9·0	90
1 „ 7 „	5·0	57
1 „ 10 „	4·4	50

In the following table the brick joints were immersed at once and tried after twenty-eight days; the briquettes were immersed after one day and tried at twenty-eight days:—

Composition of Cement.	Neat Soorkee Cement.		Cement with equal volume of Sand.	
	Adhesive Strength.	Tensile Strength.	Adhesive Strength.	Tensile Strength.
	lbs. per Sq. Inch.	lbs. per Sq. Inch.	lbs. per Sq. Inch.	lbs. per Sq. Inch.
1 lime paste, 1 Soorkee	32·0	130	20·8	144
1 „ 1½ „	16·9	145	8·9	120
1 „ 2 „	18·8	130	7·1	116
1 „ 3 „	11·2	125	0·1[1]	156
Mean	..	132	..	134

[1] This may rise to 11·2 lbs., but at that point the strength is very capricious.

From this table it will be seen that the adhesive strength, though good within rather wide limits, decreases with an addition of Soorkee beyond 1 part, but diminishes still more rapidly when diluted with sand; while for tensile strength the proportion of Soorkee is unimportant, the cement being as strong with sand as without.

The following practical rules have been deduced from the experiments:—

(*a*) The best Soorkee cement for masonry is made with 1 of Soorkee to 1 of lime paste (or an equivalent quantity of slaked lime); after twenty-eight days under water it is stronger than the best bricks, and with stone it stands a disruptive force of 60 lbs. per square inch.

(*b*) When rapid setting is an object, the proportion of Soorkee may be increased to 2 parts, but with some loss of strength.

(*c*) When economy is an object, the cement made with 1 of

Digitized by Google

Soorkee to 1 of lime paste may be diluted with an equal volume ($1\frac{1}{2}$ part) of sand; the mortar will be as strong as good bricks.

(*d*) When greater economy is an object, as in the case of rubble masonry, 2 parts of Soorkee may be used to 1 of lime paste, and the cement diluted with an equal volume ($2\frac{1}{2}$ parts) of sand.

(*e*) Where the rubble masonry is required to be specially good, two proportions may be used: 1 of lime to 1 of Soorkee, for laying the stone; 1 of lime, 2 of Soorkee, and $2\frac{1}{2}$ of sand, for grouting.

(*f*) The latter proportion may be employed where the bricks are of an inferior quality, as it is still much stronger than ordinary country bricks.

(*g*) When the lime is hydraulic, the above proportions still hold good, but the adhesive strength of the Soorkee cement which it yields is less dependent on moisture than when fat lime is used.

On the Proportion of Actual Strength to the Tensile Strength obtained with Standard Briquettes of Mortar.

Composition of briquettes—

Shell lime slaked $1\frac{1}{2}$ = paste	1	} 1 cement.
Brick Soorkee (Sappers and Miners)	3	
Sand (vol. = vol. of mixed cement)	$2\frac{2}{3}$	1 sand.

Immersed at one day old for twenty-seven days, the tensile strain was increased by the lever testing-machine at the rate of about 5 lbs. per second, and the average breaking weight was found to be 311 lbs., or 138 lbs. per square inch. Three other briquettes were then subjected to a portion of the mean breaking weight at first, and the remainder added at intervals of time.

—	Minutes.	Proportion of Mean Breaking Weight.	—	Minutes.	Proportion of Mean Breaking Weight.
Briquette D stood for	10	·5	Briquette F stood for	20	·70
	15 more	·6		20 more	·75
	10 „	·7		22 „	·80
	15 „	·8		13 „	·85
	3 „	·9			
Total 53, when it broke.			Total 75, when it broke.		

From these and other experiments it would appear that if the breaking weight, when attained rapidly, be represented by 100, 60 could be supported for at least twenty-four hours, and 75 for a time varying from three minutes to eighteen hours, and it is probable that the permanent strength of this mortar would be little short of 50 per cent. of its breaking weight.

A. T. A.

Digitized by Google

Concrete Dam for the Geelong Waterworks.[1]

By G. GORDON, M. Inst. C.E.

(Roorkee Professional Papers on Indian Engineering, 2nd Series, vol. iv., pp. 402–404.)

The site for a new reservoir for the water supply of Geelong was chosen on the "Stony Creek," a mountain stream flowing through a steep rock country in the Steiglitz ranges. In considering the design for closing one of the gorges through which the stream passed, it was at first resolved to construct the dam of masonry, as the steepness of the rocks rendered the risk of earthwork too great. Owing to the scarcity of masons and the insufficient supply of suitable building stone, this design was abandoned and one of concrete substituted. The following proportions were adopted:—

Broken stone, 2-inch gauge	3¾
Screenings	1¼
Sand	1¼
Cement	1

The cement and sand having been thoroughly mixed and made into mortar, the other materials, well wetted, were added gradually, and the whole was incorporated in an annular trough, by small ploughs fixed in frames, which worked on a pivot at the centre.

The face of the dam is vertical for 30 feet from the top, and then has a slight increasing batter. Its thickness at the top is 2½ feet; at a depth of 5 feet it is 3½ feet; at 10 feet, 6 feet; at 20 feet, 12½ feet; at 30 feet, 18½ feet; at 40 feet, 26½ feet; at 50 feet, 35¼ feet, and at 67½ feet, the greatest depth of the foundation, it is 61 feet. The concrete was brought up in layers of 7 inches in thickness, well rammed, the surface of each layer being watered, swept, and grouted with cement before the next was put on. The dam was finally plastered outside with cement mortar of 1 part of cement to 2 parts of sand.

The work was commenced in January 1873, and was finished up to the coping in June 1874. The contents are 5,096 cubic yards, and the total cost was £17,306. The reservoir contains 22¼ million cubic feet of water, so that the cost was at the rate of about £778 per million cubic feet.

A. T. A.

On Testing the Stability of Iron Bridges.

Report on M. Lefort's Memoir by M. SAINT VENANT.

(Comptes rendus de l'Académie des Sciences, vol. lxxxi., pp. 459–464.)

A French decree orders that girder bridges shall be tested until the curve of flexure remains constant with a uniformly distributed

[1] Photographs of these works, presented by Mr. Gordon to the Institution, may be seen in the Library.—SEC. INST. C.E.

Digitized by Google

weight over each or all the bays. This weight shall be 5,000 kilogrammes per mètre for bays of 20 mètres or less, and 4,000 kilogrammes for those over 20 mètres (about 11,000 lbs. per yard for bays of 22 yards and under, and 8,800 lbs. per yard for those over 22 yards). M. Lefort, Inspector-General of Ponts et Chaussées, finds that for discontinuous girders the greatest bending moments (which must be always within certain limits) are, when calculated by the government test, sometimes above and sometimes below those the real load produces. He gives in proof of this statement diagrams taken from the pressure on the driving wheels of locomotive engines. He calculates for static forces, allowing a good factor of safety. The rule for obtaining the section of greatest bending moment is due to M. Kleitz, and was communicated by him to the Author. A table giving the moments and sum of the moments with relation to the front axle, and the distances of the centres of gravity of the various portions of the train from it, does away with calculation and trial. The Author finds that the greatest bending moment takes place, not always when a bay supports the greatest sum total of loads, but rather, and with a remarkable approximation, when the centre of gravity of the portion of the train supported is immediately over the centre of the bay. The uniform loads per linear unit capable of producing such maximum differ sensibly from those of the government decree.

For continuous girders M. Lefort uses the theorem of three moments, and deduces therefrom, that as the bending moments can only be obtained from equations, in which the local loads figure as terms of a particular form, there should be substituted for these terms an equivalent weight, expressed by the ratio of the greatest extra load that the bay under consideration could receive on the passage of a train to the span of the bay; a ratio which M. Lefort gives in a table, the values varying hyperbolically from 4,000 kilogrammes (8,800 lbs.) for a bay of 32 mètres (35 yards) to 3,000 kilogrammes (6,600 lbs.) for one of 116 mètres (127 yards). M. Lefort proposes that the government order should be rescinded.

E. B.

Account of the Rebuilding of the Bridge of Andé on the Seine.

By M. René Bonnin.

(Mémoires de la Société des Ingénieurs Civils, 1875, pp. 91 and 546.)

The bridge of Andé, carrying the road from Louviers to Ménesqueville over the right branch of the Seine on four arches, was opened for traffic in 1861; it was blown up, on the 6th of December, 1870, on the approach of the German army. The pier which had been undermined was destroyed; the other piers and the abutments were more or less injured, and the ironwork was thrown into the

Digitized by Google

river. The debris was removed from the bottom of the river in 1872.

It was decided to rebuild the bridge with four arches in cast iron, of equal spans of 98 feet 5 inches, and with stone piers similar in most respects to the original construction, and the work was commenced in September 1873. A stratum of hard chalk underlies the sand and gravel bed of the river. The ordinary depth of water is about 16½ feet, and the highest flood, above which is the springing of the arches, exceeds 38 feet. The roadway, 27½ feet above the ordinary water mark, is level, and 17 feet 7 inches wide, with footpaths on each side 4 feet 4 inches wide. The foundations for the abutments and piers consist of piles (fifty-five for each pier) driven into the chalk, the mean depth of which is 30 feet below the ordinary water level; the piles are connected at the top by oak beams, upon which an oak platform, 4·3 inches thick, is fixed, 6·75 feet below ordinary water level, resting also upon a layer of concrete. The space between the piles had been filled with rubble stone, and a rubble mound had been deposited all round the piers, up to the ordinary water level, to protect them. In order to examine the foundations of the piers, the rubble mound was removed, as far as necessary, by dredging. A dam of piles, with concrete backing up to 5 feet below ordinary water level, was formed from the bottom; an inner lining of stakes, with planks fixed horizontally to them, was placed on the concrete, and the interval between the outer piles and the inner lining was filled with concrete up to 3½ feet below ordinary water level, to which point the piles were subsequently cut off. From thence to the top of the dam, 11 feet higher, the interval was filled with well-punned earth, and the rubble mound was re-formed outside. The water was then pumped out to a little below the planking; the piers were taken down, and as no damage had been done to the planking or piles, the piers were rebuilt on the old foundations, and the abutments repaired. The piers at their upper part are 38 feet 5 inches long, and 9 feet 10 inches broad.

The centrings were made for two openings only, and after the first two arches had been erected they were transferred to the other openings, being supported on piles. Each opening is spanned by three cast-iron segmental arches, having a rise of one-tenth of the span, composed of seven segments of ⌶ section 2 feet 7½ inches in height, the flanges of the two external arches being 7·87 inches broad and 1·02 inch thick; the web is 0·75 inch thick; the flanges of the middle arch are 11·02 inches broad and 1·6 inch thick, and the web is 1·26 inch thick. The arches rest on cast-iron bedplates cemented to the springing stones. The three arches over each opening, placed 12 feet 10½ inches apart, are connected by sixteen cast-iron braces, 12 feet 9 inches long, of an inverted ⊤ section, 8½ inches broad, and from 5 to 8½ inches in depth and ¾ inch thick. On the haunches of the arches there are open-work castings supporting the wrought-iron girder beams, which carry the brick arches bearing the roadway and footpaths. The

Digitized by Google

parapets are of wrought-iron lattice-work, with cast-iron standards. The arches have an extra rise of 3·26 inches, to allow for deflection when subjected to the permanent and moving load, and the usual addition of 1·3 inch for arches of that span. The calculations of the strains of the bridge are given in detail in the Paper, and also an account of the testing of the bridge on completion, the results of which agreed very nearly with the calculated effects.

The dead test load, obtained by sand spread evenly on the bridge, was 82 lbs. per square foot, and the rolling load was a wagon with rails, weighing 10·8 tons; the greatest deflection was 0·63 inch in the first case, and 0·236 inch in the second.

The cost of removing the damaged work, including the coffer-dams and pumping, was £7,545; and the cost of rebuilding was £17,144. The length of the bridge, including abutments, being 470 feet, the cost of rebuilding per superficial yard was £12 10*s*.

L. V. H.

The Foundations of the Saulze Bridge. By M. PAUL BONHOMME.

(Annales des Conducteurs des Ponts et Chaussées, March 1876, pp. 39–48, 1 pl.)

The Saulze iron bridge, which crosses the Durance with a single span of 230 feet, rests on abutments founded on gravel 23 feet below low water. The foundations for the abutments were excavated by the aid of compressed air. A chamber without a floor was constructed of iron plates strengthened by angle irons and gusset plates, 25 feet 3 inches long, 20 feet 4 inches broad, and 7 feet 2½ inches high. The top of the chamber was formed of iron plates riveted to the under side of six wrought-iron girder beams, which spanned the chamber, and to the top of the beams were fastened iron plates, forming the floor of another chamber, slightly smaller in area, with sides of sheet iron, and open at the top. The top of the lower chamber was connected with an air-chamber by a vertical cylindrical shaft, 3 feet 5 inches in diameter, of sheet iron, with a ladder inside, and upon which the air-chamber rested. The air-chamber was circular, 7 feet 2½ inches in diameter, and 7 feet 10½ inches high. Adjoining it, on opposite sides, were two small crescent-shaped chambers, having pipes with stopcocks connecting them with the air-chamber and with the external air, so that by admitting air by the one pipe or letting it out by the other, an equilibrium of pressure could be established between either of the outer chambers and the air-chamber or the outer air. The doors of communication being opened, the men could then get in or out of the air-chamber, and the excavated material could be removed without much alteration in the pressure of the compressed air. The air was compressed by a force-pump worked by a portable engine; the pressure was small at first, and even towards the close of the

Digitized by Google

works never exceeded $\frac{7}{10}$ atmosphere. A dam protected the site of the works from the floods of the river. The caisson was placed on the site of the abutment, the air compressed, and the water forced out. The excavation was then commenced by workmen in the lower chamber, and whilst the caisson was being sunk the upper chamber was filled with rubble masonry, except close to the shaft, which was left free to allow of its removal. When the caisson had been sunk to the level of the bottom of the foundations and the excavation had been completed, the lower chamber was filled with concrete, the iron shaft was taken up, and the whole filled with concrete.

The cost of the foundations was as follows:—

	£.
Putting up workshops, plant, and preliminary works	537
Scaffolding and dams	93
Ironwork for caissons	1,300
Erecting the caissons	110
Sinking the caissons	727
Masonry and concrete	368
	3,135
Contractor's profit	313
Sundry expenses	152
Total cost	£3,600

The depreciation of plant during the execution of the works is reckoned at one-fifth of its total value, and is the amount at which the cost of plant is estimated in the first item.

The quantity of excavation was 866 cubic yards, and of masonry and concrete 914 cubic yards.

The foundations of the Vichy bridge, which crosses the Allier in six spans, were excavated in the same manner, and carried to a similar depth below low water. The masonry in the foundations amounted to 2,813 cubic yards. The following table shows a comparison between the cost of the foundations of each bridge per cubic yard of masonry:—

Heads of Expenditure.	Saulze Bridge. £. s. d.	Vichy Bridge. £. s. d.
Workshops, preliminary works, and depreciation of plant	0 11 9	0 6 2
Temporary bridges, or deviation of watercourse, and scaffolding	0 2 0	0 6 8
Ironwork for caissons	1 8 5	0 19 7
Erecting the caissons	0 2 6	0 5 4
Sinking the caissons	0 15 11	0 14 4
Masonry	0 8 0	0 7 9
Contractor's profit	0 6 10	0 6 1
Sundry expenses	0 3 4	0 2 10
Total expenditure in foundations per cubic yard of masonry	3 18 9	3 8 9

The higher proportionate cost of the foundations of the Saulze

Digitized by Google

bridge was due to the greater cost of carriage of plant and materials to the site of the works, to the greater thickness of the iron plates used, and to the increase in the price of iron, whereas the amount of masonry put into the foundations was considerably less than at Vichy.

The expenditure on temporary bridges, scaffolding, and putting the caissons in place was necessarily much larger at Vichy, as the piers had to be founded in the bed of the river.

L. V. H.

Viaduct over the Valley of the Luech. By M. CHABASSU.

(Annales Industrielles, Jan. 16, 1876, p. 70, pl. 5–6.)

The railway between Nismes and Saint-Germain-des-Fossés, upon which this masonry viaduct is built, crosses, in the first part of its course, some deep valleys, which have been spanned by viaducts from 157 to 246 feet in height. The Luech Valley viaduct carries a single line, and is composed of two parts, comprising in all twenty-nine semicircular arches; it is built upon a curve of two radii, believed to be the smallest yet used, the radius of the first part, which crosses the deep valley, being 787 feet; the radius of the second part, built upon a peak of rock running out into the valley, is 656 feet. The smallness of the curve was dictated by the economy which would attend building upon this peak.

The twelve arches of the first part of the viaduct have a span of 45·9 feet, and are supported upon piers, seven of which are about 96 feet high to the springings. The bases of the piers in the bottom of the valley are carried up with nearly vertical sides to one level, from which the tapered portions spring with a batter transverse to the centre line of the viaduct of 1 in 16·6, the other sides battering 1 in 33·3. Owing to the small radii upon which the structure is built, all the piers are trapezoidal in section, and the transverse upper and lower axial dimensions are 14·8 and 26·6 feet respectively; the greatest height from the bottom of the valley is 153·2 feet. The whole of this portion is built of scapple-dressed freestone.

The second part of the viaduct, that built upon the peak, does not exceed 59 feet in height; the piers are of rubble masonry, with hammer-dressed angle stones, and the arches of scapple-dressed masonry.

The thickness of the arches of the first part is 3 feet, including a covering of fine concrete 4 inches thick, which is spread over the whole of the arches and counter-arches, from end to end of the structure, and upon which the filling is laid. The outer voussoirs are 1·3 and 0·82 foot deep, together 2·13 feet, built so as to break joint. The outer voussoirs of the small arches are alternately 1·64 and 1·0 foot in length, 'toothing' into the rubble masonry parapet walls. The length of the viaduct is 1,314 feet, the first part being

Digitized by Google

721 feet, and the width is about 15 feet; there are two gradients, one of 1 in 200, and one of 1 in 400.

For the erection of the high piers and large arches, a platform was built 46 feet high, supported upon timber scaffolding, and carrying rails upon which travelled two cranes, worked by steam, and of such a character as to dispense with scaffolding above the platform. At the upper part of the framing a mast was suspended, near its centre of gravity, and capable of oscillating so as to command the tops of the piers and the supply trucks running on a lower platform, provided with rails. The extremity of the mast carried a pulley, upon which ran the lifting and guiding chains. The total height of these cranes was nearly 115 feet, and they were found simple and efficient for such work.

All the sand and stone used were obtained on the spot, some of the latter being taken from the excavations for the foundations of the piers and abutments, which stand upon the natural rock, some of the footings being levelled and some stepped. The masonry was calculated to weigh in block 137 lbs. per cubic foot, giving a pressure of 51·3 lbs. per square inch at the springing of the large arches, and of 85 lbs. per square inch at the foundations of the piers. The whole work was completed in nineteen months, at a cost of about £23,400, or about £2 per square yard of elevation, measured over all.

W. W. B.

The Narrow-gauge Mountain Railway from Rostoken to Marksdorf in Hungary. By Paul Klunzinger.

(Allgemeine Bauzeitung, vol. xl., pp. 45–56, 3 pl.)

The Austro-Hungarian Blast Furnace Company own extensive beds of iron ore near Rustoken, at an elevation of 920 feet above the Kaschau-Oderberger railway, and in 1872 it became the Author's duty to lay out a locomotive line for the transport of an estimated yearly output of about 50,000 tons of ore to the station at Marksdorf, where the roasting was carried on; the gauge of the new line was optional, as no transfer of rolling stock between the two lines was necessary. The line was carefully laid out, but, owing to the nature of the country, extremely circuitous. The greatest bank, however, was only about 33 feet, whilst all tunnelling was avoided. The geological formation was decomposed slate and red sandstone. It presented a rough and abrupt outline, necessitating curves of 164-feet radius. The higher portion of the line was about 3·1 miles long with a rise of 1 in 375, the total length being 12½ miles, and the average gradient 1 in 40. The width of the gauge being 2 feet 4½ inches, and the wheel base 5 feet 3 inches, the minimum radius of 164 feet was practicable, for Von Weber found that, in constructing the Bröhthal railway, with a speed of about 9 or 10 miles an hour, the minimum radius could be 148 feet, the gauge being taken at 2 feet 8½ inches. Deducting

Digitized by Google

the number of non-working days and allowing for gradients, &c., it was found necessary to compose every train of fifteen trucks, carrying 5 tons each, with a capacity of 3·27 cubic yards, and with a speed of nearly 5 miles an hour. The length of the trucks was twice the wheel base, and the breadth rather less than double the gauge, the height being half the breadth. These dimensions were arrived at from the specific gravity of the ore, which was 2·0. The heavy weight of the ore produced considerable wear and tear and necessitated strong frames for the trucks, which were composed chiefly of iron in a proportion of about 40 or 50 cwt. per truck, and furnished with strong springs. Thus an empty train of fifteen trucks had a gross weight of from 600 to 750 cwt., which had to be dragged up an average incline of 1 in 40 for about 8 miles. As this required an engine of 15 tons, and with two wheels the load of 7 tons per axle would have required a rail of 55 lbs. per lineal yard, it was determined to use a locomotive with three wheels coupled and tender. Bessemer steel rails of 38 lbs. per lineal yard were finally adopted. The principal duty of the engine was to carry back the empty trucks up 1 in 40, and thus the break power became a serious question, the dead weight of the trucks being ingeniously used to assist in this purpose. Careful cross sections were everywhere taken when laying out the line.

Watering places along the route of the steep incline were found essential, and in erecting them the signalling stations were fixed at the same points, and when practicable they were placed near public roads, so as to lessen the dangers incident to level crossings. The natural rock was largely used for ballast, with good results. The line was begun in April 1873 and completed in September 1874. Where it is single the average width of formation is 6½ feet, but it varies with circumstances. The cuttings in rock permitted a slope of about 1 in 6; where the material for embankments was rock, the slope was about 1 to 1¼, and 1 to 1½ where it was earth. The nature of the strata forbade tunnelling. The total cost of the line, about £44,000, including rolling stock, but exclusive of land, was equal to about £3,800 per mile. The iron trucks cost about £107 each.

H. T. M.

The Breslau-Schweidnitz-Freiburg Railway in the Valley of the Oder. By H. WIEBE.

(Deutsche Bauzeitung, vol. ix., pp. 353 and 373.)

This line, about 218 miles long, enters the Valley of the Oder near Stettin, traversing it obliquely from south to north. For 40 miles in the neighbourhood of Stettin, the river abounds with branches, necessitating several bridges of long span. One of the tributaries, the greater Reglitz, enters the Damm Lake, and as all these rivers communicate with the Baltic, it was neces-

Digitized by Google

sary to examine the relation between them and the sea. Great difficulty was found in ascertaining the volume of water near Stettin. It varies considerably, from the continually shifting level of the Baltic, 43 miles off, and from the quantity brought down by the river itself. Although free from regular tides, its level is constantly subject to change, due to the force and direction of the wind; violent gales from the north-west, north-east, or north raise it nearly 5 feet, whilst storms from the opposite direction depress it more than 4 feet, showing an extreme rise and fall exceeding 9 feet. Though these fluctuations are of short duration, they are felt in the Oder as far as Schwedt, 24 miles to the south-west of Stettin, beyond which they have no effect. At Stettin the extreme range of the river is nearly 8 feet, and at Schwedt about 10 feet. Contrary to expectation, it was found that the embankment on which the railway was made through a great portion of the valley exercised no effect on the water-level.

The results furnished by previous floods indicated that at Neu Glietzen, Schwedt, and Stettin their relation is as 6, 7 and 9. Gaugings showed that the greatest discharge took place near Schwedt, where it exceeded 140,000 cubic feet per second, whilst at Stettin it was only 109,000 cubic feet per second. This is accounted for by the greater width of the valley and by a decrease in the gradient of the stream, the general level of the country at this point being only about 1·75 foot above the ordinary water line. The datum used at Stettin is only 5·4 feet above the well-known datum pile at Amsterdam.

The construction of the station at Stettin is fully described. The marshy nature of the ground gave much trouble, and care was taken to load the areas built over as equally as possible. Round each building, belts of granite blocks were laid to insure greater security in the foundations. In the lower part of the valley the ground banked over was the worst kind of bog. In some places a crust of light turf and roots floating in water had to be dug out to depths varying from 26 feet to 33 feet before any foundation could be met with; the subsoil was mostly light clay covered with sand. Two methods were adopted in forming the banks, to prevent the soft ground rising on each side. In one case, when the height of the work did not exceed 6·5 feet, the whole of the loose ground was excavated for a width equal to a base necessary for two lines of rails, and for a depth equal to the height of the bank; the stuff thus raised was thrown on each side of the trench and formed part of the bank itself. Very little sinking was found to take place. By the second method two or three parallel trenches, 3·3 feet wide by 6·5 feet deep, were excavated, and filled with sand before the earthwork was tipped for the embankment. This system was successful; great consistency was obtained, and no sinking was observed. The operation of tipping was greatly facilitated by ditches dug on each side of the embankments across the moor. A list of bridges is given, some being of considerable

Digitized by Google

length. All the abutments were built on concrete laid within sheet piling; the concrete went to the clay, and was also carried up to probable flood-level. The superstructures of the bridges were wrought-iron continuous girders, the use of scaffolding being undesirable owing to the nature of the ground.

H. T. M.

Slipping of the Tiligul Embankment on the Odessa-Balta Railway. By J. PANDER, Chief Engineer.

(Notizblatt des technischen Vereins zu Riga, vol. xiv., pp. 54–57.)

The Author gives a detailed account of the numerous slips which occurred in constructing the embankment, crossing the Tiligul ravine, at a distance of 123 miles from Odessa. At this place the railway is laid out for a double line, on a curve of 24·85-chains radius, the length of the embankment being 41 chains, the maximum height 71 feet, and the width at the formation level 27 feet. There are falling gradients from each end towards the centre, where the line is level for 10 chains. A culvert constructed of a permeable limestone, 186 feet long, 9 feet high, with an arch of segmental form and span of 7 feet, was erected at the crossing of the river Tiligul, which is usually dry during the summer months.

The railway was opened for traffic in December 1865, this embankment being then completed, with the exception of the slopes, the centre-piece having been made up with earth from adjacent cuttings, principally of wet clay intersected by beds of marl. The slopes were finished, by means of tip-wagons, during the spring of 1866, while the earth was frozen. The embankment soon showed signs of weakness, although little of importance occurred until July, when a slip of considerable magnitude, where the embankment was highest, necessitated, among other repairs, the lengthening of the culvert by 18 feet.

During the year 1867 numerous cracks appeared in the slopes, and two deep fissures, respectively 900 and 420 feet long, were formed in the crown of the embankment. These, after having been filled up, were succeeded by others, finally necessitating the shifting of the rails to the extent of 1 foot. At the same time a portion of the arch of the culvert was found to have settled 10·9 inches. At the commencement of the following year, a length of 150 feet of slope gave way, leaving many of the sleepers unsupported. The rails were moved a distance of 2 feet; but further slips occurring, all traffic was stopped during a space of twenty-four hours. Investigation showed that after percolating through the ballast, in many places 7·5 feet thick, the rain-water, instead of draining off, had burst through the slopes. With the object of remedying this, the ballast was removed, the crown of the embank-

Digitized by Google

'ment was covered with a layer of impermeable material, and lastly, sand was tipped up to rail-level.

In the year 1869 a fissure appeared, which gradually increased to 342 feet, the slopes also bulged, and at one point subsided 12 feet, the traffic accordingly being limited to one line of rails. From this time it was determined that sand only should be used for repairs, and that the slopes should be carefully trimmed and sown, to prevent settlement. As the slips still continued, a counter-dam, 240 feet long, and 12 feet broad, was thrown up along the foot of the slope at the worst places, and the culvert, which had again given way, was prolonged by timbering for a length of 18 feet. The enormous expenses attending these repairs led to a thorough investigation as to the origin of disturbance, and the institution of a fresh method of treatment.

In May 1870, the upper portion of the embankment, where the slips had taken place, was opened out and filled in with fascines. Thirty-two shafts were sunk, and deep channels cut in the slopes at the worst points. In the prosecution of these works, it was discovered that the upper part of the embankment, for a length of about 900 feet, was saturated with water, especially in the neighbourhood of the culvert. At a depth of 24 feet the soil composing the embankment was still frozen, and, as the excavation proceeded, great quantities of water exuded. Close to the culvert, at a depth of from 12 to 30 feet below the formation level, the core of the embankment proved to be of a pasty consistency, exhaling so noxious an effluvium as to necessitate frequent shifts of labourers, and preventing the sinking to a greater depth than 36 feet.

After shafts, 6 feet square in horizontal section, had been sunk, to depths varying from 10 to 44 feet, cross-cuts, strongly timbered, were excavated from the former, at right angles to the centre line, in lengths varying from 74 to 351 feet, and at depths of from 16 to 61 feet below formation, the floors of which were graded so as to get rid of the water as rapidly as possible. All these were finally filled in with fascines and sand, the timbering being withdrawn where practicable. At the foot of the slope on the left side, a trench was excavated, 528 feet long and 6 feet deep, and then filled up with fascines and stones. During the progress of these works one line only was used for traffic, the trains being limited to a speed of $3\frac{1}{4}$ miles per hour.

The cost of repairs for the years 1865–67 was defrayed by the contractor, but the subsequent expenses fell upon the company, and were as follows:—

	£.		Roubles.
1868	4,547	or	29,103
1869	15,018	„	96,121
1870	3,993	„	25,558
1871	3,542	„	22,672
1872	516	„	3,308
	27,616		176,762

Digitized by Google

Had the line in the first instance been diverted, and the original bank abandoned, the expenses would probably have been considerably less. At the commencement of the year 1873, traffic was resumed over the second line of rails, with every prospect of non-interruption.

D. G.

On the Use of Cast and Wrought Iron as a Material for Railway Sleepers. By L. KIRSCH.

(Revue Universelle des Mines, vol. xxxviii., pp. 451–477.)

The Author dismisses cast-iron sleepers with a brief notice of their advantages in point of durability in tropical climates, where timber sleepers last but a short time; and their disadvantages in humid climates and under heavy traffic.

Wrought-iron transverse sleepers were first tried in Belgium, in 1862, then in France and in Portugal, and afterwards in Germany. One of the first of them was the Couillet sleeper, like I in section, 7 inches wide, with a shallow flange at each edge, and about 8 feet long, weighing 100 lbs.; it was laid flat on the ballast, and a flange rail was bolted to it, bedded on a cushion of hard wood. The Le Crenier sleeper was also shallow in section, like ⌐¬, consisting of plate iron turned down at the edges; it was 12 inches wide, and 8 feet long, and the flange-rail, placed directly upon it, was fixed by brackets bolted to the sleeper. These and other wrought-iron sleepers were tried, and were found to be deficient in vertical stiffness, and inconvenient for the operations of packing, whilst they offered little resistance to the lateral displacement of the way.

The Vautherin sleeper, first tried in 1864, on the Lyons railway, has been very successful. It is hollow in section, of the form A, truncated, supposing the upper part of the letter to be removed, 8 feet in length, 9 inches wide over the flanges forming the base, and presents a flat bearing surface, 3·2 inches wide, for a flange-rail. It is $\frac{3}{8}$-inch thick at the centre, and is only about half that thickness in the wings. The rail is fixed to the sleeper with gibs and cotters. It is reported that the motion over the Vautherin sleepers is much easier than over sleepers of oak, and that in consequence the cost of maintenance is comparatively small. It is stated that among a number of trial rails laid under similar conditions, but some on wooden sleepers and some on the Vautherin sleeper, the percentage of defective rails was only 2·49 of those on the Vautherin sleeper, while it was 12·94 of those laid on wood. It was found that if the Vautherin sleepers were not at least 8 feet long they gave way at the ends, and that even with this length it was well to strengthen them at the angles. It was also found that large and hard ballast, such as broken stones, or broken slag,

Digitized by Google

aggravated this tendency to give way, while ballast of ashes produced a similar bad effect, and also caused the sleeper to rust. On the other hand, ballast of gravel of a marly character adapted itself admirably to the form of sleeper. On the whole, however, with the exception of the fastenings, which are rather complicated, the Vautherin sleeper offers, in the opinion of the Author, a satisfactory solution of the problem of the substitution of wrought iron for wood in transverse sleepers.

Briefly noticing the Barlow rail, the Author describes the Hartwich system—the "boldest attempt, without contradiction," that has been made. It consists of a flange-rail, 9½ inches deep, having a web $\frac{7}{16}$ inch thick, and a foot 5 inches wide. It weighs 87 lbs. per yard. The rails are fish-jointed, and are strengthened at the joint by a sole-plate, 1 foot 7 inches long, 9 inches wide, and $\frac{5}{8}$ inch thick in the centre, secured to the rails by eight bolts and nuts connected transversely by two sets, at different levels, of screwed tie-rods; the rails are laid in trenches, filled with gravel and small stones. This system has given bad results wherever it has been employed; the rails soon become curved longitudinally; and on one line, after three years and three-quarters of service, they acquired a permanent set of 1 inch, and had to be taken up. The renewals were frequent and troublesome.

The Author notices other systems, similar to the Hartwich; also compound rails, consisting of an upper table and two flanged sides, bolted together; all of which are troublesome to lay and maintain, especially in curves. Finally, he investigates the Hilf system, to which he accords the preference in every respect over other combinations of wrought-iron sleepers. It consists of two parts; an iron longitudinal sleeper, and a flange-rail of steel. It is simple, easily laid and maintained, and economical. The sleeper is in section like the letter E, bevelled at the angles, having an upper flat surface and three flanges downwards; it is 12 inches wide, and about 2½ inches deep. It can be rolled 30 feet long, and only ⅓ inch in thickness. The sleepers now employed weigh 59 lbs. per yard. The rail is 4·32 inches high, with 2·32 inches breadth of table, 3·40 inches width of flange, and $\frac{4}{10}$ inch thickness of web. It is rolled in lengths of 30 feet, and weighs 51½ lbs. per yard. It is fish-jointed, and fixed to the sleeper, with two rows of bolts and nuts, at intervals of from 30 to 40 inches. The two rails are tied to the gauge by 1-inch tie-rods, screwed at both ends, with nuts. One tie-rod is sufficient for each length of rail. The combined rail and sleeper, placed on supports 54 inches apart, can carry 18 tons at the middle, without its elasticity being injured.

M. Kirsch presents two series of tables, based on estimates, showing the first cost, and the cost of maintenance, of various systems of flange rail and wrought-iron sleeper, in which it is made apparent that, of the systems that have been tried, to the present day, the Hilf system is, in every respect, the most economical.

D. K. C.

Digitized by Google

The Heberlein Break. By M. MASSAUGE.

(Annuaire de l'Ass. des Ing. sortis de l'Ecole de Liége, vol. iv., pp. 479–482, 2 pl.)

The Heberlein continuous break, applied since March 1874, to a train running between Brussels and Luxembourg, adopts the principle of stopping a train by "work" accumulated during its motion. This is accomplished by fixing a wood-shod flat-faced wheel or roller upon one axle of one or more break or baggage-vans in a train, against which is pressed a small iron wheel, running in a suspended frame, and upon each end of the axle of which flat-linked chains are caused to wind by the revolution of the latter wheel against the wood-faced one. The chains are connected to and operate upon the breaks throughout the train by suitable levers, the force with which the blocks grip the wheels depending upon the pressure brought to bear upon, and the consequent friction between, these wheels. A cord is passed along the top of the carriages, placing the train break at the disposal of the engine-driver, as well as of the guards in the front and rear of the train. The train to which the break is applied consists of two first-class and three second-class carriages and two baggage or break-vans. Comparative trials with the Heberlein and the ordinary screw break show that the former produced, in a given distance, the greatest reduction of train speed, owing principally to its promptness of action. In the case of derailment or separation, the cord along the top of the carriages is broken, and the train stopped. This break has also been applied to the locomotive with satisfactory results; the wheel-tires are more equally worn than by a screw break, and the cost of maintenance is proved to be small.

W. W. B.

Compressed-Air Tramway Car. By M. MÉKARSKI.

(Mémoires de la Société des Ingenieurs Civils, 1876, pp. 55 and 101.)

The employment of compressed air for locomotion, relative to M. Mékarski's tramway car, has been discussed at considerable length at recent meetings of the Société des Ingenieurs Civils, in Paris. In addition to the particulars of this car already published,[1] it may be stated that the pressure in the reservoir which is charged at the beginning of the journey with air of 25 atmospheres, is reduced by wire drawing to a constant initial pressure of 5 atmospheres in the cylinders, where it is worked by means of variable expansion-gear.

The maximum quantity of work by expansion is performed by air of 25 atmospheres, supposing that the temperature is main-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xliii., p. 383.

Digitized by Google

tained constant, when it is expanded in the cylinder from that pressure down to atmospheric pressure, and M. Mékarski supplies the following data, based on such a hypothesis:—

	Kilogrammètres per cubic mètre.		Foot-lbs. per cubic foot.
Total work	831,700	or	170,300
Back pressure of the atmosphere	248,000	,,	50,803
Work utilised	583,700	,,	119,497

If, on the contrary, the air be expanded without receiving any heat from without, the temperature falls, and the pressure diminishes much more rapidly during expansion, the effect of which is that a considerably less quantity of work is performed and is utilised, thus:

	Kilogrammètres per cubic mètre.		Foot-lbs. per cubic foot.
Total work	428,400	or	87,740
Back pressure of the atmosphere	115,200	,,	23,590
Work utilised	313,200	,,	64,150

—little more than half the first value of work utilised. The need for a supply of heat to the air, not so much before the period of expansion, but continuously during expansion, is thus rendered apparent, and M. Mékarski supplies the required heat by the preliminary mixture of steam with the air, as already described, the heat of the steam being absorbed by the air as it is liberated by condensation during expansion. That the reheating of the air by the steam is done with a considerable degree of efficiency is proved by the fact that of the above 120,000 foot-lbs. of work that would be realised under the last conditions, 82,000 foot-lbs. are actually realised. This quantity of work was ascertained by measuring, by means of a dynamometer, the resistance to traction on a given tramway, together with the weight moved and the distance traversed.

The cooling of the heated water, and the diminution of pressure of the air in the reservoir, take place simultaneously in the course of the journey, and thus the elements of the mixture may be maintained in sensibly constant proportions.

The experimental compressor, a pump the piston of which works in water (*pompe à piston d'eau*), delivers a volume of compressed air equal to from 55 to 60 per cent. of the volume described by the piston, making from twenty-five to thirty double strokes per minute, and moving at a speed of from 70 to 80 feet per minute. For comparison, it is stated that Colladon's compressors, employed at the St. Gothard Tunnel, yield 80 per cent. of the volume, compressing to 8 atmospheres, with a speed of piston of about 250 feet per minute. The experimental compressor produces 1 cubic foot of compressed air at 25 atmospheres, by an expenditure of engine-power, measured by the friction-break, not exceeding 410,000 foot-lbs. The work actually realised (82,000 foot-lbs.) is just one-fifth of the force expended in compressing the air.

Digitized by Google

But the work expended in producing, by compression, 1 cubic foot of air at 25 atmospheres is the same as that utilised in the reverse action of working down by expansion, namely, 583,700, as was stated above, showing a wide margin for improvement when compared with the actual break-power expended for compression, namely, 410,000 foot-lbs.

M. Mékarski calculates that the fall of pressure by wire-drawing, from 25 atmospheres to 5 atmospheres, followed by the complete expansion on a piston from 5 atmospheres down to atmospheric pressure, results in an efficiency of 62 per cent.; that is to say, a loss of 38 per cent.; and that this loss is compensated by the reheating of the air during expansion by the intermixed steam. The expenditure in thus reheating the air is only a small proportion of the total fuel consumed. The quantity of heated water supplied to the reservoir of the car, is about 3 cubic feet, at a temperature of 320° Fahr., and the car returns with about $2\frac{2}{3}$ cubic feet of water at 212° Fahr.; the difference representing the consumption of about 2 lbs. of coal, whilst the fuel consumed in charging the reservoirs with compressed air amounts to 33 lbs. of coal.

Comparing the compressed-air system with horse-traction, M. Mékarski estimates that the relative economy of the former consists only in the cost for feeding the horses; all the other charges balancing each other.

The cost for horses is 4·6*d.* per mile run; for coal, on the air system, allowing a consumption of 8 lbs. per mile run, at 28*s.* $2\frac{1}{2}$*d.* per ton, the cost is 1·25*d.* per mile, which is about one-fourth of the cost for horses. To cover interest on capital, let it be taken at 2·3*d.*, which leaves 50 per cent. economy, or, proportionally, 25 per cent. of the total expenses for traction.

M. Mékarski estimates that the cost for steam-locomotion on tramways is the same as that for the compressed-air system.

The hot-water system of motive power, in which the power is supplied by the "spontaneous" evaporation of steam from a body of water raised to a high temperature, has been preferred by many, on account of the high theoretical duty calculated to be contained within a given volume. Suppose the initial temperature be so high that one-tenth of the water may be so evaporated within working limits; then, theoretically, 9 cubic feet of heated water would supply steam capable of performing the same work as 1 cubic mètre, or $35\frac{1}{3}$ cubic feet of air at 25 atmospheres. In practice, the theoretical maximum is far from being reached. Thus, at New Orleans, the hot-water locomotive working between the city and Carrolton, on a level road, with a reservoir of 57 cubic feet, can only traverse from 5 to $5\frac{1}{2}$ miles. The locomotive now under trial on the Boulevard Bineau has a reservoir of 71 cubic feet, and has only gone $2\frac{1}{2}$ miles, when the pressure has failed. A third machine, forming a portion of the car, has been tried at Verviers, Belgium; with 50 cubic feet of reservoir space, it can only make a trip of $3\frac{3}{4}$ miles. From these data, M. Mékarski

Digitized by Google

draws the deduction that the volume of heated water necessary for the performance of a given length of journey is the same as that of compressed air of 25 atmospheres.

D. K. C.

On the Flow of Water in Pipes. By P. Boileau.

(Comptes rendus de l'Académie des Sciences, vol. lxxxii., pp. 601–604.)

M. Darcy found that the results of numerous observations on the velocity of the flow of water in cast-iron pipes, taken at the centre and at distances from it of one-third and two-thirds of the radius, might be expressed by the equation,

$$V - v = C \frac{\sqrt{i}}{R} y^{\frac{3}{2}},$$

where v is the velocity of the filaments of liquid at a distance y from the axis of the pipe, V the velocity along the axis, R the internal radius of the pipe, i the loss of head in a unit of length, and C a constant. M. Levy showed that the same results might be represented by the equation,

$$V^2 - v^2 = c\, i\, y^{\frac{3}{2}}.$$

To obtain more accurate formulæ from these experiments, the discharge of the stream in a unit of time was divided by the area of its cross section, and it was found that, taking U to represent the mean velocities thus obtained, the ratio $\frac{V - U}{\sqrt{i}}$ is constant for the same pipe, and that it varies with the diameter of the pipe and the roughness of the sides.

The relation between the velocities and the distances from the axis is given by an equation of the form

$$V - v = \gamma \sqrt{i} f\left(\frac{y}{r}\right)$$

where r is the radius of the film of liquid whose velocity is U, and γ the before-mentioned ratio; and considering that $f\left(\frac{y}{r}\right) = \left(\frac{y}{r}\right)^n$, since it is a function which becomes zero when $y = o$ and unity when $y = r$, the equation resolves itself into

$$v = V - \frac{\gamma}{r^n} \sqrt{i}\, y^n$$

when the flow is uniform and the pipes not very small.

Digitized by Google

The value of U is expressed by the equation,

$$U = V - \frac{2}{n+2}(V - w),$$

where w is the velocity of the film in contact with the sides.

The loss of head in a unit of length, where the flow is uniform, is proportional to the height due to the difference between the greatest and least velocities of the filaments of liquid, and for pipes of equal diameters is proportional to the friction on the sides.

If the value of $r = R\sqrt[n]{\frac{2}{n+2}}$ is substituted for r in the equation for the velocity it becomes

$$v = V - \left(\frac{n}{2}+1\right)\gamma\sqrt{i}\left(\frac{y}{R}\right)^n$$

and the following value has been found for γ,

$$\gamma = a R^{\frac{1}{2}} + b R^{\frac{5}{2}},$$

where a and b vary only with the roughness of the sides.

L. V. H.

Researches on the Form of the Longitudinal and Cross Sections of Gravel-bearing Rivers. By H. STERNBERG.

(Zeitschrift für Bauwesen, vol. xxv., pp. 483–506.)

Valleys and stream-beds are exclusively formed by the action of flowing water, which carries with it solid bodies, when their frictional resistance to motion is less than the force due to the impact of the water. Supposing the boulders (*gerölle*) to be of similar form, the resistance to motion increases as the third power, while the moving force of the water increases as the second power of the linear dimensions. Hence, the boulders at any part of a stream, flowing at a given velocity, may be divided into two parts, one moving with the water, the other remaining at rest. It follows, that at any one point the size of the boulders depends on the maximum velocity at that point.

The force acting on a solid body due to the impact of the water is

$$P = \epsilon\frac{w^2}{2g}F\gamma,$$

where w = velocity of water, F = area of projection of the body normal to the direction of flow, γ = weight of a cubic unit of water,

Digitized by Google

and ϵ is a co-efficient depending on the form of the body. Taking $\epsilon = 0{\cdot}8$

$$P = 40{\cdot}77\, F\, w^2 \text{ for metric measures} \quad . \quad . \quad . \quad . \quad . \quad (1)$$
$$[\ = {\cdot}775\, F\, w^2 \text{ for English feet and lbs.}]$$

If the boulder is assumed to have the form of an ellipsoid of revolution, whose longer axis $2\,a$ parallel to the direction of flow is twice as great as its smaller axis $2\,b$

$$P = 128\ b^2\, w^2 \text{ for metric measures} \quad . \quad . \quad . \quad . \quad . \quad (2)$$
$$[\ = 2{\cdot}43\, b^2\, w^2 \text{ for English feet and lbs.}]$$

The frictional resistance to motion, taking the co-efficient of friction for stone on stone at $0{\cdot}5$, is

$$P = 5026\, b^3 \text{ for metric measures} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$
$$[\ = 314\, b^3 \text{ for English feet and lbs.}]$$

Equating the moving force and resistance,

$$w = 4{\cdot}43\sqrt{2\,b} = \zeta\sqrt{2\,b}$$
$$[= 8{\cdot}04\sqrt{2\,b}\,]$$

The Author then determines independently the value of ζ, by the aid of Dubuat's and other experiments on the size of materials transported by water. As a mean value, he finds

$$\zeta = 4\ [= 7{\cdot}24 \text{ for feet}].$$

The abrasion of a boulder is assumed to be proportional to its weight in water and to the distance it has travelled. In travelling a distance dx the abrasion is proportional to $b^3\,(\gamma_1 - \gamma)\,dx$ if γ_1 is the weight of a unit of the material and γ that of a unit of water. The abrasion is also proportional to $-d\,(b^3)$

$$-d\,(b^3) = \eta\, b^3\,(\gamma_1 - \gamma),$$

where η depends on the material of the boulder.

If x_0 and b_0 are corresponding values, and also x and b, integration gives

$$\log.\ \frac{b}{b_0} = \lambda\,(x - x_0) \text{ or } b = b_0\, e^{\lambda\,(x - x_0)} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where, for brevity, λ is put for $\frac{1}{3}\,\eta\,(\gamma_1 - \gamma)$. For obtaining the value of λ

$$\lambda = \frac{1}{x - x_0}\ \log.\ \frac{b}{b_0} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

or using equation (3)

$$\lambda = \frac{1}{x - x_0}\ \log.\ \frac{w^2}{{w_0}^2} = \frac{2}{x - x_0}\ \log.\ \frac{w}{w_0} = \frac{2}{x - x_0}\ \log.\ \frac{u}{u_0} \quad (6)$$

Digitized by Google

where u and u_0 are put for the mean velocities at the cross sections considered. Since in general the velocity decreases in going down stream, or $u_0 > u$, the co-efficient λ is negative.

An equation to the longitudinal profile of the stream is then obtained. Let Q = the discharge of the stream per second; F its sectional area; p the wetted perimeter; r the mean radius; a the slope or fall per unit of length; and u the mean velocity.

$$F u = Q \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

$$u = k \sqrt{\frac{F}{p}} \sqrt{a} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

k is not strictly constant, but will be treated as if it were so. Considering the surface of the stream in a longitudinal section to be represented by a curve referred to rectangular axes of co-ordinates, the abscissa of any point x is horizontal and positive in the direction of flow, and the ordinate y is vertical and positive downwards.

From (4) $b = b_0 e^{\lambda(x - x_0)}$

From (3) $w = \zeta \sqrt{2b}$, or putting $u = \frac{4}{3} w$

$$u = \frac{4}{3} \zeta \sqrt{2b} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Combining these

$$u = \frac{4}{3} \zeta \sqrt{(2 b_0 e^{\lambda(x - x_0)})} = u_0 e^{\frac{\lambda}{2}(x - x_0)} \quad . \quad . \quad . \quad (10)$$

introducing the value in (7)

$$F = \frac{Q}{u_0} e^{-\frac{\lambda}{2}(x - x_0)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

In the two last equations the mean velocity and the area of section are simply dependent on the abscissa x.

Again, from (11) and (8), since $a = \frac{dy}{dx}$

$$dy = \frac{u_0^{\frac{3}{2}n}}{k^n} \left(\frac{p}{Q}\right)^{\frac{n}{2}} e^{\frac{3}{4}n\lambda(x - x_0)} dx. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

This is the general differential equation to the form of the surface of a stream in the longitudinal section, and it gives by integration different forms according as $\frac{p}{Q}$ varies.

The Author examines the three most usual cases, and shows that the surface of the stream is a logarithmic curve. He then examines in detail the probable value of the co-efficient λ. There are three independent ways of determining λ, all of which present difficulties in practice. The value of λ, from observations on the Rhine, is determined by all three methods, and the average arrived

Digitized by Google

at is $\lambda = -\cdot 00000476$ mètre [$= -\cdot 00000145$ foot]. The formulæ are then compared with the curve representing the longitudinal section of the Rhine obtained by levelling.

Ideal Cross Section of a Stream.—For a stream in permanent régime there corresponds to a given discharge a given wetted perimeter, p. In the maintenance of the longitudinal profile the regular removal of the materials of the bed worn down by travelling is necessary. For most watercourses the wetted perimeter appears to become too great when the water is low, and too small when the water is high. In the former case the boulders are not kept in motion, and in the latter they are transported impetuously. In the low-water condition gravel beds are formed, between which the stream meanders. If the section of the stream narrowed downwards it might fulfil the condition, that for all states of the water the mean velocity would remain constant. The transport of gravel would then be continuous. The form of such a cross section has already been determined by Woltmann, and may, perhaps, be useful in the construction of watercourses. The mean velocity would be constant if $\frac{F}{p} = r$ = constant for all states of the water. Then $d\,F = r\,dp$. Consider the section to be symmetrical on each side of the vertical axis of co-ordinates. Let h = vertical and b = horizontal co-ordinates of a point in the curve forming the sides of the channel.

$$d\,F = 2\,b\,d\,h;\ dp = 2\,\sqrt{(d\,h^2 + d\,b^2)}$$

$$dh = db\,\frac{r}{\sqrt{b^2 - r^2}} \quad \ldots\ldots\ldots\

Cevennes, and other mountain ranges. The basin of the Garonne above Toulouse is peculiarly adapted for a rapid discharge of flood waters; and though the extent of this portion of the basin is only one-seventh of the Seine basin above Paris, the discharge at Toulouse on June 23rd was six times that of the Seine at Paris in its greatest floods. The highest floods of the Garonne at Toulouse have almost always occurred in the spring or early summer, as at this period floods due to excessive rainfall are increased by the rapid melting of snow on the high mountains. The floods of the tributaries on the right bank of the Garonne below Toulouse generally occur in the autumn, and were not considerable in June, with the exception of the Agout, a tributary of the Tarn.

All the rivers rising in the Pyrenees, as far as the Corbières, were in flood on June 23rd, and the bridge of Tarbes, over the Adour, was swept away. Those, however, situated to the north or west of the central table-land of France did not rise considerably; indeed summer rains seldom produce much effect on them. A general rainfall like that of June 23rd is not unusual. Another heavy rainfall occurred on Sept. 9–13, 1875, over eight departments of France, which produced a flood along portions of the course of the Herault greater by 2 or 3 feet than any previously known, and a very high flood on the Allier and on a few small rivers; but the rain was not sufficiently universal to cause general floods.

L. V. H.

On the Flood of the Seine in February–March, 1876.

By M. BELGRAND.

(Comptes rendus de l'Académie des Sciences, vol. lxxxii., pp. 596–598.)

The basin of the Seine consists of 7,500 square miles of impermeable strata, and 22,860 square miles of permeable strata. The rains falling on the impermeable strata always produce the highest floods at Paris: the floods caused by tributaries flowing through permeable strata take some days longer in reaching Paris. The river consequently remains in flood for some days, and if during that period another rainfall occurs a higher flood follows, so that the river may continue rising during whole months from the effects of successive floods without a possibility of predicting when the waters may subside. The floods of the Rhone, the Loire, and the Garonne, on the contrary, are generally the result of one rainfall; their rise is rapid and high, but of short duration. The flood of the Seine in February and March, 1876, was caused by seven floods of tributaries: each flood causes the river to rise for three or four days, so that by the aid of the telegraph the highest rise of the river can be predicted three or four days beforehand. The river, which at the commencement of the flood on the 16th of February stood at 2 feet 7½ inches on the gauge of the bridge of Austerlitz, had risen to 19 feet 4 inches on the 12th of March.

Digitized by Google

M. Lemoine and the Author gave notice that it would rise on the 16th to 21 feet 4 inches, which is 1 foot 4 inches higher than the great flood of the 18th of October, 1872, and only 3 feet 7 inches below the flood of the 3rd of January, 1802—the highest in this century.[1]

L. V. H.

Hydraulic Experiments at Roorkee.

By Capt. Allan Cunningham, R.E.

(Roorkee Professional Papers on Indian Engineering, 2nd Series, vol. iv., pp. 1–111.)

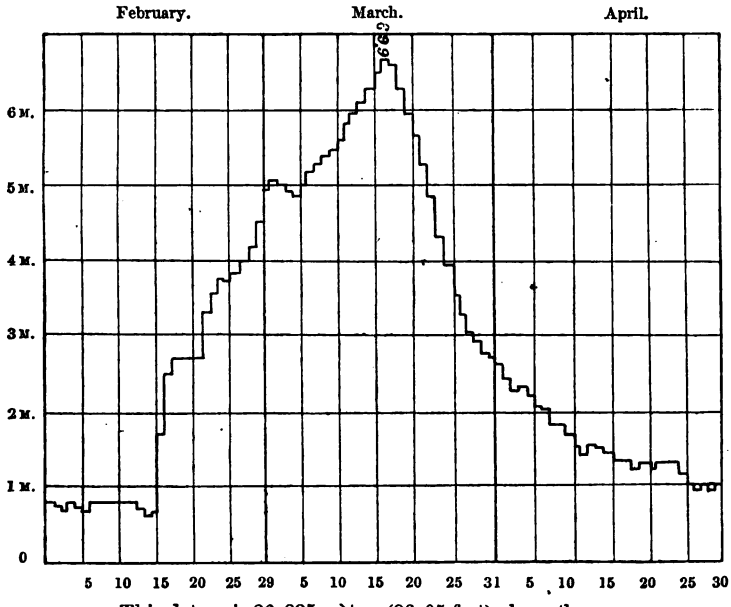
The Author gives full details, tables, and diagrams of some thousands of velocity measurements conducted by him, as a volunteer, during the cold weather of 1874–75, on the Ganges canal close to Roorkee, the Government providing the necessary funds.

Admitting the great value of the Darcy-Bazin and of the Mis-

---

[1] In a letter to the Secretary of the Inst. C.E., M. Belgrand adds: "We announced on the 14th of March, that this flood would reach 6·70 mètres (21 feet 11·7 inches) on the gauge of the bridge of Austerlitz on the 17th of March; it reached in reality 6·69 mètres (21 feet 11·3 inches); so that our announcement was strictly realised. I add a diagram of the flood, the total quantity of which I have calculated to reach nearly 4,231,440,000 mètres cubes (5,535,000,000 cubic yards)."

The Seine at Paris (bridge of Austerlitz) 1876.



This datum is 26·235 mètres (86·05 feet) above the sea.

Digitized by Google

sissippi experiments, it is contended that further experiments are essential, since the former dealt with small channels, or distributaries only, whilst the latter were chiefly on motion of too complex and tumultuous a character to admit of unravelling from them the laws of fluid motion. In the Author's opinion it is necessary to fully investigate the simple case of steady uniform motion in large regular channels; and for such an investigation the main irrigation canals of India appear to offer special advantages. As a first instalment of such a work, the present series of hydraulic experiments were undertaken by Captain Cunningham, on a straight reach of 6 miles of canal of comparatively uniform section. This reach comprises three descriptions of channel, viz:—

(1) Trapezoidal channel, in earth, 3 miles long, 150 feet average width of bed.

(2) Trapezoidal channel, masonry sides (steps), clay bed, 2 miles long, 150 feet width of bed.

(3) Rectangular twin channels, in masonry, 932 feet long, each 85 feet wide.

(4) Trapezoidal channel, same as (2), $\frac{1}{4}$ mile long.

The experiments were confined to channels (2) and (3); and at the former of these, surface velocities alone were measured. Floats were, in all instances, used for determining the surface velocities, those for general use being of deal, 3 inches in diameter and $\frac{1}{4}$ inch thick, and those for use next the bank 1 inch in diameter and $\frac{1}{8}$ inch thick. Ropes were stretched across the channel to define the length of run (which ranged from 50 feet at the centre to $12\frac{1}{2}$ feet near the bank), and various methods of observing the time of passage of the floats over their run were tried, the system finally adopted being as follows: One observer sat with a chronometer in front of him midway between the two ropes. The second observer, standing opposite the upper rope, warned the timekeeper of the approach of the float, and shouted just as it passed under the upper rope; he then walked down to the lower rope, and standing opposite, shouted again just as the float passed under the lower rope. The timekeeper entered the number of chronometer beats counted, just as he caught each shout, to the nearest half-second.

The Author observes that in all practical treatises results are based on the hypothesis that the motion of water is steady; but his experiments prove, on the contrary, that this hypothesis is not even approximately true. Thus in a carefully-conducted experiment, the velocity of one hundred and twenty floats, dropped into the centre of the stream at five-second intervals only, was found to range from 4·35 feet to 3·27 feet per second; and the experiments generally conclusively proved that there are changes in the velocity of water from instant to instant.

Many observations were made to determine the surface velocity curves in the masonry channels of the Solani aqueduct. It was soon found that the variation was slight for the central three-quarter width of the channel and great near the banks, hence the

Digitized by Google

distance apart at which the velocities were measured was gradually reduced from 10 feet at the centre to about 6 inches at the sides. The particular curves were of irregular shape, and disagreed in detail, the position of the line of maximum surface velocity varying over half the width of the stream; in fact, the disagreement between each curve was so great as to render it at first sight apparently a hopeless task to deduce any simple laws from such variable data. After a time, however, it seemed probable that the curves interlaced in such a manner as to be of literally constant area, and upon testing this, it was found that the mean curve of the velocity measurements was strikingly regular. After various trials, it was deduced that the actual mean curve of the observations, as regarded the chambers of the Solani aqueduct, was closely represented by the equation:

$$\frac{u^4}{u_0^4} + \frac{y^4}{b^4} = 1,$$

where b = half the breadth of the channel, y = abscissa of any point on b (measured from centre), u_0 = central mean velocity = max. ordinate, u = mean velocity at any point whose abscissa is y = ordinate of mean curve. This curve may be called a "quartic ellipse," and its area, taken across the channel, represents the surface discharge = 0·927 × mean central velocity × width of channel. The Author observes that the above curve is probably only a particular result, applying to a rectangular masonry channel with a depth of water of about $\frac{9}{85}$th of its width.

The surface velocity curve in the channel along the Solani embankment (2) was also symmetrical about the centre line, but exhibited a striking irregularity, inasmuch as there were two lines of maximum velocity about 40 feet to the right and left of the centre. The Author is of opinion that this might possibly result from the influence of the central pier of the Solani aqueduct, though 3,000 feet distant, or from the slightly increased depth of the channel on each side of the centre line.

For measurement of sub-surface velocities, a spherical ball, 3 inches in diameter, of heavy wood, attached by a wire to a surface float of deal, 3 inches in diameter by $\frac{3}{8}$ inch thick, was generally employed, although other methods, described by the Author in detail, were at times substituted.

The irregularity of the mid-channel vertical velocity curves was no less marked than that of the surface curves; but, though differing in detail, the areas were tolerably constant. In a symmetric section the central velocity curve is approximately a parabola to within a short distance of the bottom; but the law of variation of the position of the axis and of magnitude of parameter cannot, the Author states, be properly investigated until further experiments are undertaken. For similar reasons, little confidence can be put in any now existing formulæ or tables purporting to give the value of the bottom velocity. The mid-channel mid-depth velocity was found practically equal to the mean velocity

Digitized by Google

in the central vertical plane; and the Author advises that the first work in future experiments should be to ascertain if this is true of all the vertical planes, and if a 'rod' sunk to nearly full depth measures approximately the mean velocity of its plane of motion. Various practical suggestions, with acknowledgments of assistance from Major Lang, R.E., and others, brings this exceptionally valuable contribution to hydraulic science to a conclusion.

B. B.

On the Closing of an Arm of the Danube. By J. PRUCHA.

(Stummer's Ingenieur, vol. iv., 1875, pp. 205, 217, 229.)

The arm of the Danube where these operations were carried out is on the left-hand shore, a short distance below Pesth. At the upper end it has a breadth of about 1,400 yards, with an average length of about 37 miles, and a depth of a few feet, and is only navigable by small vessels; it forms with the Danube the island of Czepel.

The inspectors regulating the Danube trade, who undertook the matter, commenced the work at about 23½ miles down stream from the northern end of the island, by throwing up a dam from 30 to 36 feet above the summer flow. This dam was carried from the mainland across to the island, over which it was continued at an increased height so as to protect the island from inundations. The depth of the water on this line is from 2 to 3 feet in the driest seasons. There is a road 37 feet wide on the top of the dam, with slopes of 2 to 1 on either side to about 9 feet above the river bed. At this point toes of large stones and ballast, having slopes of 1½ to 1 and running from shore to shore, serve as a protection and support, that on the down-stream side being considerably broader and higher than that on the upper side. The up-stream face of the dam was furnished just above flood-level with a berm 12 feet wide to break the waves.

The body of the bank was composed of ballast, dredged out of the Danube above the dam. Work was commenced, on the 18th of March, 1872, simultaneously from both ends, piles being driven at the point where the vessels unloaded and tipped the ballast. By the middle of April the ends of the bank were only 180 feet apart, the effect being that the water on the up side of the stream was 2 feet higher than on the down side. The current had now become so strong that the vessels had to be moored with great care, and it was only the largest blocks of stone that could retain their position when thrown in. As the force of the current increased, even these were carried far down the stream. To meet this difficulty, boxes of stout boards clamped with iron, some containing 30 and others 60 cubic feet, were filled with stones and thrown in from the ends of the dike and from vessels moored in position. In this way, by the end of April, the two ends were brought to within 125 feet of each other, but the current had

Digitized by Google

become so rapid that the vessels employed on the work could only be brought alongside the dam at the shore ends, and were then carefully drawn up to the opening; the difference in the upper and lower water-levels was 4 feet, and the depth of water at the opening was between 7 and 9 feet. Various attempts were made to complete the work, but the following plan alone proved successful. The unfinished ends of the dam were first widened out on the up-stream side, to about 15 or 20 feet breadth, and raised to about 15 feet above the water-level, the object of these earth platforms being to protect the main body of the dam from injury, whilst they gave room for several boxes of ballast ready to be tipped into the stream. A vessel, 108 feet long by 15 feet beam, and 7 feet deep, was furnished with an upper deck, 5 feet high, made of stout timbers 2 inches thick, carried down to the keel. The interior of the vessel was strengthened by stout round balks, each of one piece, and thoroughly braced in all directions. Four holes, each 1½ inch in diameter, were now bored in the sides of the vessel, the holes being so arranged that they could be simultaneously opened by raising a lever to which was attached a closing beam. To guard against any danger from bursting, the vessel was well braced with chains, and also thoroughly caulked.

At a distance of 300 feet from the opening in the dam, a large dredging vessel was moored, as the chief base of operations, six powerful anchors being arranged so as to prevent movement in any direction. Midway between this vessel and the gap was placed the hulk before described; it was empty, and temporarily secured to the dredger in a horizontal position by six hanging chains, the length of the full chain being exactly the distance between the dredger and the dam. The object in view was to guide the vessel exactly to the spot desired, and then to sink it instantaneously. Besides the chains, there were six strong cables running over pulleys attached to each ship, the operation of guiding them being directed from the dredger. To furnish additional means of guiding this hulk laterally, three ropes were fastened on each side, and made to pass over drums fixed to a vessel moored on the left bank; whilst on the right bank some piles had been driven, to which a raft, with the necessary machinery, was fixed.

In addition to the above precaution, two ropes were carried to the ends of the dam, and there worked as above described. Previous to the actual operation, all the men were trained in their duties, and a quiet, windless day was selected. Large stones were held in readiness for throwing in immediately the vessel was sunk, and a number of the boxes filled with ballast were pitched into the hole directly the preparations for slipping the vessel had been completed. The hulk, which previous to this had been partly laden with ballast, was now filled up until the raised bulwarks nearly touched the water; the four holes on each side were then opened, and the water admitted; every man not required on the raft and vessels was sent to the ropes carried to the broad ends of the dam, and at a given signal the cables

Digitized by Google

holding back the hulk were slipped, the men keeping her well in hand on every side. The vessel moved slowly on, gradually sinking, till she touched the two ends of the dam; the six chains began to strain, and three of them snapped. In every other respect, however, the operation was a success, and immediately after its completion the water on the down-stream side began to fall. Directly the vessel touched the bottom, the water rushed furiously between its ends and those of the dam, carrying away large quantities of ballast; this loss was, however, made good from the material stored for the purpose on the dam. The hulk after sinking was only 1 foot above the water; but vessels carrying large stones were now brought up and rapidly discharged, so that by 11.30 A.M. the gap was closed, and by 1.30 P.M. the roadway over the dam was complete from end to end; the actual moving of the vessel to its site having been commenced at 10 A.M. By the afternoon the bed of the river on the down-stream side was nearly dry, every fresh leak being immediately made good. By the end of November 1872 the bank was raised 30 feet above the low-water level, and completed. Two thousand four hundred cubic yards of large stones were used in the toe of the bank on the down-stream side, and 553 cubic yards on the opposite side; the total amount of ballast was 21,333 cubic yards.

The cost of the dam was about £23,600; the operation of closing the gap by sinking the hulk, &c., involved an expenditure of £900.

H. T. M.

New Type of Movable Dam. By M. BOULE.

(Annales des Ponts et Chaussées, 1876, pp. 320–374, 1 pl.)

The ordinary forms of movable dams, such as the vertical-spar system of M. Poirée, and the turning floodgate of M. Chanoine, are not free from objections. The spars must not be too heavy for one man to lift and put in place, and thus a limit (about 11½ feet) has to be set to their length, and consequently to the height of the dam. In addition to the supports of the turning gates, their sills, and aprons, a bridge carried on upright iron beams is required, higher up the river, from which to work the gates; and though the limit of height might reach 13 feet, or possibly 14½ feet, the cost of this method of construction increases rapidly with the height of the dam. In these systems it is necessary to remove the dam entirely when the upper level of the river approaches the level of the bridge, which is placed close to the top of the dam in M. Poirée's method to enable the spars to be within reach, or when the balanced gates of the navigable channels in M. Chanoine's system are opened by the rising water. In the proposed type the bridge and the dam are united, the uprights carrying the bridge being placed at such a distance apart as to admit of simple paddles being let down between them, the number of paddles between each support being regulated by the height to which it is

Digitized by Google

designed to keep up the water. The paddles are raised by a chain working on a windlass and guided by a crab, beam, and pulleys on the bridge; the paddles, when lifted, are put on a small trolly running on the bridge, which conveys them to a shed so as to be out of the way till required: they are lowered by a pole, having a fork at its end, clasping the top of the paddle, which is pushed down by the man in charge, aided, if necessary, by the chain and windlass. This plan was tried last year at the foot-bridge of the dam of Port-à-l'Anglais from which the turning floodgates are worked. The navigable channel of Port-à-l'Anglais is closed by twenty-six of M. Chanoine's floodgates; the level of the upper water is usually kept up to 12½ feet above the sill, and it sometimes rises to 13½ feet; the fall, which varies with the level of the river below the dam, exceeded 10 feet in September 1874. The upright wrought-iron supports, twenty-six in number, carrying the bridge, are 15 feet 7 inches high, and 3 feet 7·3 inches apart; they are formed of channel iron, 3·15 inches broad, 1·38 inch deep, and 0·275 inch thick. The channel iron forming the side of the framing facing the stream is vertical, at the back it is inclined, reducing the breadth from 10 feet 2 inches at the bottom to 3 feet 11 inches at the top; these vertical pieces are joined by horizontal channel irons at the bottom and top, and the framing is braced horizontally and diagonally. Three oak paddles, 3 feet 6½ inches wide and 4 feet 3 inches deep, are placed one above the other across each opening between the uprights; T-irons are fastened to the ends of their back faces, which serve to strengthen them, to bear against the front vertical channel irons of the uprights, and to keep the paddles in place. The paddles of the two lower rows are 3·15 inches thick, and of the top row 2·36 inches thick. The windlass in ordinary use on the bridge was employed, with the necessary additions for lifting the paddles. The cost of adapting the new system to the bridge at the dam of Port-à-l'Anglais was £200, or £6 7*s.* 5*d.* per lineal yard. Comparing the cost of the floodgates of M. Chanoine with the cost of the ordinary paddles used in the recent experiments, and taking into consideration the fact that by the proposed system the masonry of the walls and of the apron might be considerably reduced, it appears that the saving in adopting the new system would be £55 per lineal yard, or nearly 30 per cent. in the construction of the dam of Port-à-l'Anglais, which amounted to £188 8*s.* per lineal yard. The cost of twelve dams, 9 feet 10 inches high, on the Seine between Montereau and Paris, amounted to £112 5*s.* per lineal yard; on the proposed system a dam 13 feet high would cost £133 9*s.* per lineal yard; so that a dam one-third higher would only cost one-fifth more. In the experiments at Port-à-l'Anglais the three paddles of one opening had to be lifted consecutively, as the requirements of the navigation did not permit at the time of their being lifted in rows, as would be done on the approach of a flood, so that the lower paddles were raised through a full fall of water. The time occupied in raising the upper paddle was from

Digitized by Google

two to three minutes, the second paddle from five to six minutes, and the bottom paddle from eight to ten minutes; but these latter times would be considerably less in the ordinary course of working. Other advantages of the new system are the simplicity of construction, and the facility and economy of repairs, all complicated parts being above the water; and though the first cost would amount to about the same as that of M. Poirée's system for the same height of dam, yet higher dams could be constructed, the bridge could be raised above the level of floods, and the dam could be closed or opened more or less at any time. The lowering or raising of the dam would be gradual, thereby not exposing the river to sudden floods below or dangerous shoaling, and the fall being equal along the dam, the backwater eddies and the scour would be reduced.

L. V. H.

On the Laying of a Submarine Water Pipe in the Harbour of Pola. By J. PRUCHA.

(Stummer's Ingenieur, vol. iv., p. 241.)

The first great dry dock built for the Austrian Government was constructed on the Island of Olives, in the port of Pola, in connection with several maritime establishments.[1] Other buildings being contemplated, it became necessary to secure a good water supply from the mainland, the island itself presenting no natural sources. The distance from the shore is about 290 yards, the maximum intervening depth of the water at low tide being about 56 feet. Any communication with the land, except a submarine tube, would have been liable to constant interruption, especially during the prevalence of north-west winds. The water was taken from a spring supplying Pola; and soundings having been made, it was ascertained that the harbour bed had a fall of 1 to 1½ for a short distance until it attained a depth of 56 feet, when it continued nearly horizontal to the island, where it rose again at the rate of 1 to 1. The sea-bottom was covered with decomposed tufa, 2 to 3 feet thick, resting on a uniform surface of rock. It was decided to use a lead pipe, of 2-inch inside diameter by about ¼ inch thick, and having a length of 316 yards. The pipe was laid in lengths of 9 feet, joined by a copper ring, over which there was a brass flange with screws of the same material, the whole being enveloped in well-tarred hemp before being fitted together. At every third joint there was an iron ring, for letting down each length, and for attaching a buoy to mark the line. For the purposes of the work two large coasting vessels were firmly united by a platform 42 feet long by 30 feet wide, from which the jointed

[1] A description of the Pola Dock, Basin, and Railways, by Mr. H. E. Towle, Assoc. Inst. C.E., was given in the Minutes of Proceedings Inst. C.E., vol. xxxii., pp. 65–75.

Digitized by Google

lengths of pipe were let down. The vessels were moved by chains worked from the shore; and as they progressed, an apparatus attached to the platform dredged a channel in the sea-bed. The pipe on the shore was of cast iron, to which the leaden one was screwed at low-water line, and the united vessels were then moved on 27 feet at a time, dropping the pipes into the dredged channel until the island was reached, when the junction with the cast-iron pipe was effected at the mainland. After this main had been laid some time, it was torn up by the dragging of an anchor during a storm. A new pipe was then laid on a different system; the joints being made with a socket over which passed a band of lead, the whole being well soldered; this was done at the manufacturer's workshop, and sent in coils ready for use; incisions were made at various spots to test the joints, but all were found sound. Two vessels, larger than the former ones, were joined at a distance of 12 feet, by a platform erected to receive a drum 6 feet in diameter, resting laterally on strong oak beams. On this drum the whole pipe was coiled, an arrangement being provided to regulate the motion of the ships. The operation was successfully performed in eight hours; the average angle maintained by the pipe as it uncoiled into the sea being 45°.

Another accident happened to this pipe as to the former, but it was repaired in a few hours. In both cases divers were constantly employed to report progress.

The first operation cost £240; the second, £160, and the third £190, when the old material of the first pipe was partly used.

H. T. M.

The Improvement and Enlargement of the Port of Genoa.

By F. Ciocca and V. Chiavacci.

(Rivista Marittima, 1875, part 4, pp. 331–377, 433–480, plates 1–27.)

The port of Genoa, though recently improved by extending the outer mole, is still in a defective condition. The exterior works consist of two moles, which include an area of 301 acres, of which 128 acres are much exposed; of its internal border, about one-third, or 720 yards, are also exposed; the inner harbour is frequently in a fœtid state, and the entrance is dangerous to navigation.

A Commission lately reported that an enlargement of the harbour, to the extent of 320 acres is absolutely necessary; that its entrance should be so situated as to be accessible during the continuance of the strongest and most prevalent winds, and be protected from the littoral and marine currents, and that the surface of the harbour should be absolutely tranquil at all times. The local conditions of the port and place are as follows:—The north wind prevails for from one hundred and twenty to one hundred and fifty days in the year; the south and south-west, for one hundred and ten to one hundred and thirty days; the

Digitized by Google

remaining days are calm, or the winds are variable; winds from the east and west blow for only fifteen to twenty days annually: only the south-east and the south-west winds exert any seriously disturbing influence on the harbour. The recent extension of the Molo Nuovo has afforded some protection against the former; hence the chief object of any further improvement will be protection against the latter, which when reflected from the cliffs of Carignano renders the present approach highly dangerous; at the same time these conditions require that the new harbour-entrance shall not be exposed to the direct action of either of these winds.

The currents affecting the harbour are of three classes: 1. The internal currents, changing the water of the harbour, due to the rise and fall of the tides, the influx of land drainage and stream-water, and the variations of temperature and atmospheric pressure: these are of no importance as regards navigation, although they are from a hygienic point of view; hence the interior works, docks, and basins should not interfere with this motion. 2. The Mediterranean or littoral current from east to west along the shore; this in calm weather has a velocity of only $\frac{1}{4}$ mile per hour. 3. The wave-currents accompanying the direction of the wind, when coming from the south-west, are so prejudicial to ships entering the port that mariners generally are obliged to keep well off the coasts of La Cava and Delle Grazie before entering. The tendency to shoaling in the port is principally due to the sediment brought down by the Bisagno, and the transporting influence of the littoral current, combined with that of the wave-currents from the south-west.

From a consideration of these conditions, the Commission rejected two classes of projects submitted to them, namely, those having entrances opening to the east, and those having detached breakwaters which allow of two entrances, and would not provide sufficient shelter at the same expense.

Of the approved type there are six projects, all having the harbour-entrance opening to the west-north-west; the details of the scope and estimated cost of each of these are given in the accompanying table (p. 273). Several of these projects have in combination with them a plan for a large additional harbour of about 247 acres extending along the shore of S. Pier d' Arena, which is considered by the Commission to be beyond the present requirements, and to involve an unjustifiable expense. Plans of the proposed exterior works of these six, as well as of the remaining twelve projects, with their modifications, accompany the report. The Commission make the following remarks on those of the preferred type:—

1. That of Descalzi, proposed in 1861, was the first design suited to the local conditions. The general direction of the new outer mole is in a curved line from the battery della Stella to the entrance, or passage between it and the prolongation of the existing outer mole. The entrance is 2,187 yards from the mouth of the Bisagno, and is not liable to be affected by its silt.

Digitized by Google

COMPARATIVE COST of PROJECTS for the EXTERNAL WORKS of ENLARGEMENT of the HARBOUR of GENOA.

Projectors.	Area protected.	Entrance.				Dimensions of Moles.					Cost. The lire at 25 = £1.	Time necessary.
		Width.	Depths.			—	Length.	Depths.		Section.		
			Min.	Max.	Mean.			Max.	Mean.			
	Acres.	Yards.	Yds.	Yds.	Yds.		Yards.	Yds.	Yds.	Square yards.	£.	Years.
1. Molinari Descalzi . . .	375	918	17	31	24	New works	2,078	32	22	1,276	637,488	5·7
						Prolongation of old . .	328	18	17	921	80,664	..
						Total	2,406	..	..	..	718,152	..
2. Ratto.	452	907	11	23	17	New works	2,548	28	21	1,237	764,176	6·5
3. Barret	358	656	9	23	15	New works	2,154	25	21	1,190	668,724	4·7
4. Argenti	642	1,093	14	34	21	New works	3,806	34	21	1,130	977,968	9·7
						Prolongation of old . .	109	..	17	887	26,488	..
						Total	3,915	..	..	..	1,004,456	..
Modified (2) *c*.	513	743	18	28	22	New works	3,040	30	19	1,011	794,000	6·9
						Prolongation of old . .	328	18	17	921	80,664	..
						Total	3,368	..	..	..	874,664	..
5. Comm. of Naval Captains .	311	732	18	28	22	New works	1,739	28	20	1,092	478,628	4·5
						Prolongation of old . .	328	18	17	921	80,664	..
						Total	2,067	..	..	..	559,292	..
Modified (2) *b*.	368	929	17	29	22	New works	2,111	30	21	1,204	621,536	5·8
						Prolongation of old . .	328	18	17	921	80,664	..
						Total	2,439	..	..	..	702,200	..
6. Parodi.	417	765	20	32	25	New works	2,187	34	22	1,250	661,232	6·5
						Prolongation of old . .	437	20	18	972	111,392	..
						Total	2,624	..	..	..	772,624	..

Digitized by Google

2. The design of Ratto is an enlargement of that of Descalzi, and dispenses with the lengthening of the Molo Nuovo. Its outer mole begins from the same point, but after a sharper curve of about 547 yards in length, takes a straight and economically contrived course as regards depth to within 875 yards of the Capo di Faro, where it leaves a width of passage of 907 yards between itself and the Nuovo Molo. The cost per acre of the accommodation afforded is very low. The defect of this design is that the harbour-entrance is not sufficiently central.

3. The design of Barret is less comprehensive, and less costly, than either of the former. His proposed interior arrangements of docks, quays, and basins are considered preferable to those of the remaining designs, and are generally adopted by the Commission. His outer mole, starting from La Cava, is 2,154 yards long to the outer entrance of the harbour; there are also two short transverse moles, reducing the inner harbour entrance to only 164 yards, and this is considered objectionable for navigation and unsuited to the circumstances.

4. The design of Argenti is more extensive than any of the others. It includes the entire deviation of the Bisagno torrent, previously proposed by the Municipality, and the utilisation of 74 acres on its banks, as well as the accommodation of a proposed line of railway towards Piacenza in connection with the S. Gothard line, thus saving a tunnel estimated to cost £40,000. His outer mole begins at the west of the deviated Bisagno, and is 3,806 yards long, extending to within 919 yards of the Capo di Faro. This design is costly, and would require ten years for its execution; hence, though highly commended, it is considered beyond the probable requirements of Genoa. The modification of this design, though less expensive, is open to the same objection.

5. A commission of naval captains proposed a modification of the design of Descalzi, by which the estimated cost and the time of execution will be reduced to £560,000, and to four and a half years, while affording nearly the amount of shelter considered to be necessary for Genoa. It is also proposed to make a portion of the outer mole of this design in artificial blocks instead of faced random stone, so as to allow of more easy removal, in case an extension of the harbour should become desirable.

6. In the design of Parodi the outer mole begins at the west bank of the Bisagno, and incloses a large surface. Although exceeding the requirements, it is perhaps better for so extended a harbour than any of the foregoing; it does not interfere with the Bisagno, and its entrance is well suited to the conditions.

In summing up their opinions the Commission announce that the design of Descalzi is excellent; that the economy of the modified design of the commission of naval captains renders it preferable to any; that the designs of Ratto, Barret, and Parodi are extremely good; and that, under a more flourishing state of finances, the design of Argenti would be the best that could be adopted.

In selecting a section suitable to the proposed outer mole, the

Digitized by Google

Commission condemn the almost vertical type adopted at Dover on the score of its high cost; and object to the Miller type—that of a vertical wall built on a mass of random stone—as not having received enough sanction from experience. Breakwaters with long side-slopes, as in England, are objected to on account of their expense; and those of the French and Italian type, with side-slopes of from 2 to 1 to 1 to 1, are considered inefficient, and requiring expensive maintenance. The mixed section adopted by Pascal at Marseilles, consisting of random stone faced with artificial blocks, having a batter of $1\frac{1}{2}$ to $1\frac{1}{3}$ to 1, is preferred; the top thickness is fixed at 25 yards. These data are adopted in the comparative table of the projects; the calculation of the time necessary for their execution is based on the assumption that 392,000 cubic yards of material could be furnished annually from the quarries of La Cava de San Benigno and La Cava di Levante. The prices are based on those at Marseilles and of previous work at Genoa; they are, for random stone 7 lire, and artificial blocks 25 lire, per cubic mètre (4*s*. 2*d*. and 15*s*. 3*d*. per cubic yard); of which the quantities per lineal mètre of mole are about 100, and 50 cubic mètres, after allowing for a deduction of one-fifth for interstices in the random work.

As to the interior works of the harbour, quays, docks, &c., an examination of the trade statistics of Genoa, from 1870 to 1874, showed that the mean annual amount of merchandise was 1,387,240 tons. An inquiry into the development of trade at Liverpool, Antwerp, Amsterdam, Rotterdam, Bremen, Hamburg, Marseilles, Venice and Trieste, and into the results likely to accrue from the connection of the Italian with the continental railways, as well as other proposed improvements, gave sufficient evidence that the actual requirements of the Port of Genoa should shortly be increased to the reception of 2,000,000 tons, and eventually perhaps to 4,000,000 tons. Assuming the latter as the basis on which the designs for the interior works should be drawn up, the Commission proceeded to determine the amount of accommodation wanted. For mooring quays, a breadth of 5·5 yards is considered sufficient; for town wharves used by coasting craft, 21·8 yards; for commercial quays, a breadth of 65·6 to 71 yards, of which 5·5 yards must be roofed; and for timber and coal quays, 55 to 65 yards. Hydraulic cranes are considered necessary at the two latter kinds of quay, and manual cranes at the town wharves. The length of quay walling available between the shore ends of the moles, including the eight bridges, and those of the existing basins will be 8,311 yards, the length of mooring quay on the two moles being 1,093 yards. This length may be afterwards extended as requirements demand. The quays will communicate by rail with the station of S. Pier d'Arena and the western station; the necessary tunnels will cost £104,000. The whole of these interior works, including swing bridges, covered stores, cranes, trams and roads, will, if carried out in the mode proposed by Barret, raise the total estimated cost of the proposed harbour from £560,000 to £1,200,000.

L. D'A. J.

Digitized by Google

On the Chemical Composition of the Sewage Liquid and Effluent Water of the Dantzic Irrigation Works.

By O. HELM.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, vol. vii, p. 721.)

The drainage works of Dantzic and their connections being now nearly completed, the sewage liquid has become sufficiently constant in character to be worthy of analysis. Samples were taken on seven days, from the 8th to the 14th of July, 1875, one day only being rainy, and were afterwards mixed and analysed.

The liquid was slightly muddy, depositing a light grey sediment; the mud could not be entirely removed by filtration, but the water was otherwise colourless. The odour of the fresh-drawn liquid was slightly putrid; after being allowed to stand for four days, sulphuretted hydrogen was evolved, and a slight precipitate of sulphate of iron gave a black colour to the sediment. The sediment contained an earthy insoluble matter, impregnated with iron and phosphoric acid, many organic forms, amorphous mineral precipitates, and living infusoria.

The following is the result of the analysis.

The liquid, when freed from sedimentary matter, had a hardness of 12·8°, of which 6·8° were permanent and 6·0° temporary. Its constituents were:—

PARTS IN 100,000.

	In solution.	In suspension.	Total.
Silica	1·80	12·80	14·60
Lime	11·09	2·74	13·83
Magnesia	1·41	0·09	1·50
Potash	4·44	..	4·44
Soda	8·77	..	8·77
Sulphuric acid	2·37	..	2·37
Chlorine	6·97	..	6·97
Oxide of iron, Alumina, Phosphoric acid	4·75	4·70	9·45
Carbonic acid, Loss	7·30	2·27	9·57
Inorganic matter	48·90	22·60	71·50
Organic matter	19·40	35·60	55·00
Total dry residue	68·30	58·20	126·50
Actual ammonia	..	..	5·32
Organic nitrogen	..	..	1·16
			132·98

The liquid consists of the sewage of a town of about eighty thousand inhabitants, and the refuse of four thousand houses,

Digitized by Google

diluted with surface drainage and storm overflows amounting to about 400,000 cubic feet, or 12,366,000 kilogrammes, which is delivered daily at the pumping station. This contains 134 cwt. of organic and 174 cwt. of inorganic matter, of which 62 cwt. are manurial substances. The value of the latter is thus estimated:—

			£.	s.
15 cwt.	2 qrs.	of nitrogen	68	0
4 „	3 „	phosphoric acid . . .	7	7
10 „	3 „	potash.	4	3
31 „	0 „	lime not given.		
62 cwt.	0 „		79	10

The liquid is utilised in the irrigation of some land about 2 miles ($\frac{1}{2}$ mile Prussian) from Dantzic, part of which can be cultivated, while the other part is useless sandy soil. The suspended matter delivered on to the land forms a crust on the surface, and the dissolved matter is partly utilised in impregnating the soil, the remainder being exhaled into the air; while the organic matter undergoes a chemical change. The liquid, after utilisation, is allowed to soak or filter through earthen banks, and is then collected in drains, from which it is conducted in channels and conduits to Weichselmünde and Heubude.

The samples of effluent water taken from the drains were of a yellow colour, slightly muddy, but translucent, resembling Sauterne. The water was inodorous, but had a slightly putrid flavour. After being allowed to stand for a day it threw off reddish-yellow flakes; subsequent settlement did not, however, alter its muddy character. Its reaction was slightly acid, but this disappeared after long boiling, through the removal of the carbonic acid contained in it. It had 7·6° of hardness. It contained 7·6 parts per 100,000 of lime and magnesia, and from 1·07 to 1·19 part of ammonia, but generally neither nitric nor nitrous acid. In two cases, after a few days, traces of nitric acid were discovered, but the ammonia began to decrease until it disappeared in twelve days. The filtered effluent water contained from 8·4 to 8·6 parts per 100,000 of organic substances, free from nitrogen, as obtained by burning; but the permanganate of potash method indicated a greater amount. The inorganic matter amounted to 37·1 parts per 100,000, including 4·74 of chlorine, 1·75 of sulphuric acid, and traces of phosphoric acid. The suspended matters, deposited as fine brownish-red mud, when heated and dried at 212° Fahr., were found to contain 59·1 per cent. of organic matter, 23·3 of oxide of iron, 15·4 of silica and fine sand, 0·9 of carbonate of lime, and 1·3 of alumina. The organic matter consisted of diatomaceæ, and broken cellular tissue of amorphous forms of several kinds; also two species of algæ, which were recognised by Professor De Bary, of Strasburg, as Leptothrix ochracea, a spirogyra, and Anthophysa Mülleri.

An examination of the analyses of the effluent sewage liquid

Digitized by Google

indicates chemical changes that can only be explained after an investigation into the qualities of the irrigated soil.

The irrigated land, which at first sight appears to be pure dune-sand, contains a mouldy ferruginous sand, locally known as Fox-sand, which is partly decomposed by the ammonia and other salts contained in the effluent water, and is carried by them. Like lignite, it is a vegetable deposit of the Miocene period; it is generally loose and friable, but sometimes adherent in masses. Its colour varies from brownish-red to reddish-yellow. Under the microscope it resembles ordinary sea-sand; each grain, however, had an external casing of a colour varying from dirty-brown to yellow, a portion of which can be removed by immersion and ordinary agitation in water, while the remainder can only be detached by violent agitation in water, or by strong acid.

Washing in water produces 0·873 per cent. of a reddish precipitate, which sinks slowly, and is only removable by long-continued filtration. This, when taken in large quantities, exhibits a few forms of cellular structure, and fine oval grains of sand. It is partly soluble in weak brine, and when neutralised with acid disengages a reddish-brown substance.

The following are the constituents of the brownish-red Fox-sand:—1·740 per cent. of organic humous matter, 0·296 of oxide of iron, 0·236 of alumina, 0·025 of lime, 0·163 of silica.

The samples thus analysed completely explain the effect of the Fox-sand on the effluent water drained from the irrigated land. One portion of the humus of the Fox-sand is removed by the water of the sewage liquid, and passes away in so fine a state that it soaks through the soil with the water, and is deposited in the drains, forming a sediment in which the organisms, Leptothrix and Anthophysa, are found. Another portion is dissolved by the ammonia of the sewage liquid, and, after giving it a yellow colour, also filters through into the drains with the effluent water.

These organisms in the effluent water are useful in indicating its condition; for, although the former algæ can exist under circumstances which afford the simplest combinations of ammonia, carbonic acid, water, and certain salts for subsistence, the latter can only live and vegetate on the organic substances which have remained intact in the effluent water. Professor F. Cohn mentions that threads of Stereonema are found in most spring-waters, and that Stereonema-vegetation, even if it be compatible with a certain degree of impurity in the water, is never to be met with in putrid offensive water.

The foregoing examination also points to the conclusion that, after the irrigation has been carried on for a longer time, the effluent water will continue to improve; that a more compact humus will gradually form on the irrigated land, and more completely retain the organic matter of the sewage liquid.

L. D'A. J.

Digitized by Google

The Results of Sewage Irrigation at Dantzic. By Dr. Lissauer.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, vol. vii., p. 728.)

Sewage irrigation was commenced at Dantzic towards the end of 1871; the acreage then brought under irrigation being 1·89 acre; 7·57 acres in 1872; 15·7 in 1873, and 31·4 in 1874; this latter amount being about half the acreage necessary to cover the costs, which include pumping machinery for raising the sewage of the lower part of the town, and about one quarter of the acreage that will probably be eventually irrigated. The experience already gained is sufficient to furnish satisfactory replies to the more important questions, such as, the sufficient purification of the effluent water, the sanitary condition of the neighbourhood, the practicability of irrigation in the depth of winter, and the quality of the grass and vegetables grown on the sewage-farm.

The daily supply of sewage liquid, three quarters from the city refuse and the remainder from surface drainage, is 4,428,000 gallons. At first it amounted to 369,000 gallons, and was raised by pumps making fifteen strokes per minute and lifting 205 gallons at each stroke; the former representing a supply of 41 gallons per head from a population of eighty thousand, and of 5,500 gallons per acre irrigated in 1874.

The sewage is conveyed in a cast-iron pipe 10,100 feet long, to a cistern on the irrigated farm, from which its flow on to the land is regulated. The liquid is nearly clear, of a grey colour; it has a faint odour in summer like that of refuse kitchen water; and its specific gravity at a temperature of 59° Fahr. is 1000·5. Its analysis thus compares with an average taken of those of fifty English towns given by the Rivers Pollution Commission:—

	Dissolved Matters.	Organic Nitrogen.	Ammonia.	Nitrites and Nitrates.	Total combined Nitrogen.	Suspended Matter.			
						Chlorine.	Inorganic.	Organic.	Total.
Dantzic . .	68·3	1·16	6·46	..	6·48	6·97	22·6	35·6	58·2
England . .	72·2	2·20	6·70	0·003	7·73	10·66	24·2	20·5	44·7

The land on which the sewage is now utilised was originally so valueless that it let at about 4½*d.* per acre; it is now rented by the contractor at 31*s.* 6*d.* per acre on a thirty years' lease. The soil is principally dune-sand with an admixture of Fox-sand; the subsoil water rises to within 5 feet of the surface, while the sand on the surface is so light that it is blown about by the wind.

Digitized by Google

The sewage liquid, after a few hours, forces out any air from the land in bubbles, and then sinks rapidly into the subsoil, leaving on the surface and in the pores of the soil both the suspended and a portion of the dissolved matters, but washing out and carrying away some of the chlorine, iron, and humous substance contained in the soil. A portion of the matter with which the soil is impregnated is utilised in supporting vegetation, and a portion is rapidly oxidised by the air. The result of continued irrigation has been to increase the depth of humus, or vegetable soil; and this is clearly shown in the samples of soil irrigated; the irrigation of the first year merely introducing veins of humous matter into the soil, while that of several years produces a clearly defined stratum.

Experiments on samples of the soil prove: 1st. That all suspended matters as fine as grains of starch are completely retained by it. 2ndly. That if the relative speeds of percolation through fine sand be taken as 1·0, through rough bog earth as 0·454, through loose loam as 0·192, and through close loam as 0·023, then the speed of filtration through soil irrigated for one year is as 0·76; for two years as 0·526; for three years as 0·454, or equal to that of bog earth; while the soil irrigated for three years is affected to the depth of 6 inches. 3rdly. That the matters removed from the soil by the sewage liquid consist principally in the colouring substance of the Fox-sand; and that the amount is steadily diminishing every year, while the effluent liquid becomes gradually clearer and brighter. In determining experimentally the absorbing powers of the soil, the most concentrated form of sewage, simple urine, was filtered through samples of the soil; the amounts of chlorides, phosphates, and sulphates before and after filtration, as well as the specific gravity in each case both of the urine and its effluent, being accurately determined. The co-efficients of absorption obtained were, for pure sand, or previously unirrigated sandy soil, 2·7; for soil after one year's irrigation, 6·5; after two years, 7·7, and after three years, 10·3. The experiments further showed that a crust of only 0·98 inch of garden soil or grass roots raised the co-efficient of absorption of sand from 2 to 5. Also that the absorption of the phosphates increased markedly with the longer continuance of irrigation, while that of the sulphates increased slightly, and that of the chlorides hardly at all; thus demonstrating that the amount of chlorides in effluent water is not a correct measure of its degree of purity, but proving that the purity of the effluent water increases with the longer continuance of irrigation.

An examination of the analyses of the sewage liquid by Dr. Helm (*ante*, p. 276) furnishes a ready reply to the question of the sanitary condition of the latter. The English Rivers Pollution Commission decided that water is sufficiently clean to enter rivers and public watercourses, when it contains less than 3 parts of suspended inorganic matter, 1 part of suspended organic matter, 2 parts of organic carbon, and 0·3 part of organic nitrogen per

Digitized by Google

100,000. With the exception of the organic carbon, which was not estimated, the results fall within the prescribed limits; further, the presence of the algæ places it, as regards putridity, in the class of waters fit for drinking. No annoyance is ever found to proceed from the irrigation, except a faint odour on hot days. In 1873 there happened to be an outbreak of cholera in the villages of Weichselmünde and Heubude, situated between 1 and 2 miles from the irrigated farm-land; and this was at one time erroneously attributed to the neighbourhood of the sewage irrigation. The official report of Dr. Hirsch, who was specially appointed by the Goverment to examine the matter, however, entirely exonerates the sewage-farm, and attributes the cholera to the faulty arrangements for the sewage of the villages themselves. The mortality tables of these villages from 1865 to 1874, which give the percentage of deaths due to each class of disease, also afford a proof that the health of the population did not suffer in any way that could be attributed to irrigation, during the years in which it was practised.

The extreme cold of winter has not prevented the continuance of sewage irrigation at Dantzic, the coldest place in which it has yet been applied. During the first winter, the temperature fell as low as 9°·5 Fahr., and was frequently 18° and 23° Fahr., while the temperature of the sewage liquid on arriving at the farm was never below 43° Fahr. Crops of rye-grass were grown throughout this winter, and only on one occasion did the water on them remain frozen on the surface for a few days. The second winter, that of 1873–74, was particularly mild, the temperature never going below 18°·5 Fahr. The third winter was exceptionally severe, the temperature being 10°·75 Fahr. at the lowest, and frequently from 16° to 5°; while the temperature of the water of irrigation never went below 41°, and generally varied between 45° and 54°. These facts prove that the sewage liquid never freezes in the pipes and channels; that the irrigation of grass meadows is practicable with an air-temperature as low as 9°·5, and that the utilisation and purification of the sewage liquid is practicable under the extremest cold at Dantzic. The results of experience in sewage irrigation at Bunzlau for the last twenty-five years, although carried on since 1740, also prove that, when sewage liquid is conducted in pipes below the surface, it preserves a uniform temperature, which approximates to the mean monthly temperature of the air.

The farm at Dantzic has been highly productive. In 1871 no less than from four to six cuttings of grass were obtained on a previously sterile soil, while the best land in the neighbourhood only yields two cuttings. The crops mostly grown are Italian rye-grass, and summer rye. In 1873 part of the land was converted into a vegetable garden; the yield of the various vegetables being thus: turnips, 224 to 248 bushels per acre; rape and beet, 11 bushels per acre; mustard, 3 cwt. per acre. Cabbage, asparagus, and cumin were also grown, as well as barley, oats, maize, and

Digitized by Google

rapeseed. Both the grass and the vegetables were excellent in every respect; the latter being supplied to the patients of the Marienkrankhaus without any detriment to their health. The establishment of plantations of trees has been deferred until further experience can be gained from those of Breslau and Bunzlau. The results of the English mode of applying sewage in irrigation are hence not only hygienically successful, but also highly productive.

L. D'A. J.

The Hydraulic Motors of Switzerland. By W. Weissenbach.

(Die Eisenbahn, vol. iv., p. 9.)

In an article, specially prepared for the Philadelphia Exhibition, the Author gives a tabulated list of turbines and water-wheels employed in the twenty-two cantons of Switzerland, expressing their value in HP. The total of this list is—Large turbines: Girard, 14,855 HP.; Jonval, 11,444 HP.; tangent-wheels, 3,045 HP.; water-wheels and small turbines, 41,006 HP. Total, 70,350 HP. These numbers represent the maximum work, the average lying probably between two-thirds and three-fourths of that represented in the table. The industrial cantons Zurich, Glarus, St. Gallen, Zug, Basel, and Aargau chiefly work the large turbines to the extent of over 20,000 HP., Uri and Tessin employing, in consequence of the St. Gothard Tunnel, respectively 1,200 HP. and 990 HP.; while the agricultural cantons, such as Appenzell, Bern, Luzern, and Vaud use the smaller wheels. The Author calculates that the work performed by these motors could not be supplied by steam-engines for less than £500,000 per year in coal alone, without including the cost of the engines, and the greater cost of maintenance and attendance. It is estimated that there are over 6,000 turbines having under 10 HP., 214 working between 10 and 50 HP., 77 between 50 and 100 HP., 71 between 100 and 200 HP., and 29 of over 200 HP.

The total work done by each river is set forth in the following list:—

Rivers in the area of the		Rhine	61,643 HP.
,,	,,	Doubs	658 ,,
,,	,,	Rhone	3,480 ,,
,,	,,	Tessin	3,630 ,,
,,	,,	Moësa	150 ,,
,,	,,	Maira	180 ,,
,,	,,	Inn	609 ,,
			70,350

The following is a list of the motors of more than 50 HP.

Digitized by Google

worked by these rivers, without counting those worked by their tributaries:—

River.	HP.	Quantity of Water in Gallons per Second.		System of Motors.
		Per Motor.	Per Establishment. Maximum.	
Rhine . . .	1,151	100 to 1,300	4,290	2 Girard, 5 Jonval.
Thur . . .	3,469	396 „ 880	880	5 „ 8 „
Töss. . . .	2,017	187 „ 550	770	17 „ 4 „
Glatt and Aa	1,227	120 „ 880	888	9 „ 3 „ 2 water-wheel.
Limmat . .	1,267	880 „ 2,150	2,200	1 „ 9 „ 2 „
Linth . . .	1,616	268 „ 792	792	7 „ 9 „
Sihl	716	120 „ 308	308	3 „ 2 „ 1 „
Reuss . . .	2,306	187 „ 946	5,500	4 „ 11 „
Minor Emme	468	242 „ 605	605	2 „ 3 „
Lorze . . .	1,460	123 „ 550	1,122	3 „ 2 „ 1 tangent-whl.
Aar	600	673	1,346	.. .. 2 „
Major Emme	1,072	440 to 891	1,826	6 „ 3 „
Birs	1,425	170 „ 1,320	1,320	4 „ 7 „
Rhone . . .	100	4,400	4,400	1 „
Tessin . . .	960	55	220	4 „
Saane . . .	600	638	1,276	2 „

The Author also gives a table comparing the work done by different rivers as to their length, the HP. of the motors exceeding 50 HP. per kilomètre, the fall of the river, the quantity of water per second, and the maximum amount of water used per establishment in percentage of the average low water. Other tables give the natural power of each river at low water in kilogrammètres per second per kilomètre, and the percentage of such work utilised by the rivers; also the heights of falls of water exceeding 15 mètres, with their HP., the system of motor, and the river area.

J. D. L.

On the Mechanical Properties of Saturated Vapours in Vacuo.

By C. Antoine.

(Comptes rendus de l'Académie des Sciences, vol. lxxxi., p. 574.)

The Author submits the following as being general formulæ for all saturated vapours, A, B, and C being the co-efficients special to each vapour. The volume, V, is supposed to be in litres, the temperature, t, to be given in degrees centigrade, and the tension, p, in atmospheres.

Digitized by Google

$$p\,V^{1\cdot1} = \text{constant } D$$
$$p\,V = E\sqrt{t+B}$$

the co-efficients D and E having the values

$$D = \frac{(100 \times A^5 \times C)^{1\cdot1}}{76} \quad E = \frac{A^{5\cdot5} \times C \times (100)^5}{76}.$$

E. B.

On the Value of the Co-efficient of Expansion of Superheated Steam. By M. Croullebois.

(Comptes rendus de l'Académie des Sciences, vol. lxxxi., p. 592.)

The Author commences by remarking that M. Zeuner, admitting *à priori* that the equation of the adiabatic curve of superheated steam is of the form $p\,v^m$ = constant, has assigned to m the value $\frac{4}{3}$, which MM. Hirn and Cazin have found to agree with their experiments. M. Cahours has lately determined the densities of superheated steam, under atmospheric pressure, between the limits of 107° cent. and 250° cent. Employing these results, and the specific heat of steam as given by M. Regnault, the Author calculates by means of the usual thermodynamic formulæ the value of m, which he finds to vary with the temperature considerably, instead of remaining constant. This co-efficient deduced from M. Cahours' experiments agrees with that deduced by M. Moutier from those of M. Hirn; whilst its mean value between 200° cent. and 250° cent. agrees with that given by M. Zeuner. The Author concludes that the law of the expansion of superheated steam is far from being known, and that further experiment is needed.

E. B.

Hétet's Method of Purifying the Water from Surface-Condensers.[1]

By E. Lacroix.

(Annuaire de l'Ass. des Ing. sortis de l'École de Liége, 2d ser., vol. iv., p. 212.)

With surface-condensers, the boilers have been found to be subject to corrosion, while considerable deposits take place, consisting of iron associated with acid fatty matters, which are conveyed into the boilers with the water of condensation. This fatty substance is derived from the lubricant employed in the engines, which is attacked by the steam, partly dissolved, saponified, and

[1] This plan has long been known in England, and is referred to in the "Minutes of Proceedings Inst. C.E.," vol. xxvii., pp. 576–577.—Sec. Inst. C.E.

Digitized by Google

carried into the condenser. The ferruginous soap found in the boiler contains 50 per cent. of iron; and the formation of such a deposit has been a serious drawback to the employment of surface-condensers.

To prevent the passage of the acidified water into the boiler, M. Hétet tried a mixture of chalk with the water as it was pumped from the condenser. The mixture was effected with the feed-water on its way to the boiler, by a simple apparatus consisting of two cases, divided into compartments, in one of which the chalk-solution is made, and in the other the solution is mixed with the feed-water. By chemical action, the fatty substances are precipitated as an oleo-calcareous compound; and the perforations of the second chest are so adjusted as to admit of the mixture remaining there for from six to eight minutes, that the precipitation may be complete. The chalk solution and the feed-water meet in the first and lowest compartment of the chest, and are there agitated to facilitate the reaction; from this compartment the liquid passes into the second and third compartments, where it is comparatively at rest, and precipitates the insoluble compound. The feed-pipe conducts the clear water from the upper part of the third compartment, to the boiler, freed from acidity, and entirely deprived of greasy matter. The water is usually alkaline, owing to the slight excess of chalk necessary for effecting the complete saturation of the grease-acids; but the excess is not more than 70·105 grains per gallon of the purified water. The proportion of chalk is calculated at one-tenth of the weight of the lubricating oil employed in the cylinder. The trial of this system on board the "Dupetit-Thouars," with engines of 150 nominal HP., at the port of Brest, has been quite successful. The boilers are no longer attacked, and the formation of deposits has ceased.

D. K. C.

Steam Brick-kiln. By H. W. Adams.

(Journal of the Franklin Institute, 3d ser., vol. lxxi., p. 161.)

The Author converts the kiln into an oven for the equal diffusion of heat. The products of combustion from the fireplace are driven under the bottom of the kiln by forcible jets of steam of 65 lbs. pressure per square inch, from $\frac{3}{16}$-inch nozzles, introduced above the fire-door, and directed over and across the burning fuel. The jets of steam make a partial vacuum in the furnace, and draw up large volumes of air to intensify the combustion. No smoke is left unconsumed. The mixture of steam, now superheated, and gases, passes through pigeon-holed arches into the interior of the oven; and thus a plenum is maintained within it, and the hot gases penetrate to, and circulate in, every portion of it. To aid in the production of heat, a thin stream of crude petroleum is dropped

Digitized by Google

through a small opening in the crown of each furnace on to the red-hot coals, and bursts into flame. The sole of each fireplace is a plate of iron, 4 feet long by 2 feet wide, perforated with $\frac{3}{8}$-inch holes, widened to $\frac{1}{2}$ inch on the lower side. The fires are kindled with wood and large coal at first, and then the small coal is charged, and maintained at 12 inches in depth upon the grate.

It is stated that the cost for burning a kiln of two hundred thousand bricks is reduced by this process to less than one-half the cost by the ordinary process. At the time of the Report, the last of four kilns had been burned in forty-nine hours, by a man who never burned a kiln of bricks before. The bricks were all hard, including the top platting courses.

D. K. C.

Steam Railway Pontoon.

(Die Eisenbahn, vol. iv., p. 33, 1 pl.)

This vessel, belonging jointly to the Bavarian and Swiss North-Eastern railway, was built by Messrs. Escher, Wyss, and Co., of Zurich, for conveying railway carriages and locomotives across the lake of Zurich between Lindau and Romanshorn. The length is 241 feet; breadth outside the paddle-boxes 59 feet: height to freeboard 10 feet; average draught of water, when loaded, 5·6 feet. Built entirely of sheet and angle iron, with strong beams and stays, it is divided into nine watertight compartments, of which the three central ones are occupied by the machinery and engineers' cabins. The deck is entirely of iron, and has a double line of rails of 6-feet gauge. There are two pairs of diagonal oscillating Woolf engines, working independently, and each connected with a paddle-wheel, an arrangement which will allow the vessel to turn on its own axis, necessitated by the narrowness of the harbours. The engines are supplied by two pairs of cylindrical boilers, which also can be used independently, and work at a pressure of 6 atmospheres. There are water-reservoirs at both ends, which can be filled and emptied either by a centrifugal pump in the engine-room, or by a series of valves at the sides. The water can likewise be pumped from one reservoir into the other, whereby the ship may be easily raised or sunk at either end. With a full cargo of eighteen loaded goods wagons, the distance between the two harbours, about 18 miles, is completed in 1 hour 30 minutes, with a consumption of 1,320 lbs. (600 kilogrammes) of coal. By means of hinged bridges the trains are hauled ashore by locomotives. The cost of the vessel, delivered ready for service at the lake of Constance, was £24,000 (600,000 francs).

J. D. L.

Digitized by Google

Deep Sinking for Coal at Peremba in Upper Silesia.

By H. SCHANTZ.

(Zeitschrift für Berg-, Hütten- und Salinenwesen, vol. xxiii., p. 217.)

The Author describes the progress made in the sinking of three pits for a new winning called the Queen Louisa Colliery, near Gleiwitz. The object is to work a large mineral field, measuring $3\frac{1}{2}$ miles long by $\frac{5}{8}$ mile broad, containing ten workable seams of coal with a total thickness of 100 feet, and estimated to contain 120 million tons of available coal. The thickest seam, which is also the lowest, known as the "Pochhammer Flötz," is about 21 feet thick, and is expected to be reached at 455 yards below the surface, the strata having a tolerably rapid dip of from 10° to 15° from the known workings towards the new pits.

It was originally intended to sink only two pits, one 17 feet and the other $11\frac{1}{2}$ feet in diameter, the former to be used as a downcast and engine pit, and the latter as an upcast and for travelling purposes. To supply coal for the use of the sinking engines from the seam first intersected, provisional drawing arrangements were established in a division of No. II. pit; but as the drawing of coal simultaneously with the continuance of the sinking was found to be inconvenient and dangerous, a third pit is to be added for winning the shallower seams, the position being located by a bore-hole put down by the Diamond Boring Company to a depth of 290 yards. The larger, No. II., pit was intended to have two large pumping engines at the surface, but it has been decided to use a pair of Ommaney's direct-acting steam pumps and engine instead. The distance between the centres of the two pits is only about 22 yards, so that they may be easily brought into communication with each other in the event of difficulties arising during the sinking.

The sinking of the No. I. pit was commenced in September 1869, below the main adit, about 44 yards from the surface, in a loose sand known to the Upper Silesian miner as Kurzawka; the uppermost bed of the coal measures being reached at 18 yards deeper. The work was stopped by the outbreak of the war with France in July 1870, when a depth of 72 yards had been reached. In October 1871 it was resumed, and in November 1874 had reached 216 yards. For 153 yards downwards the pit is walled with brickwork, carried at intervals upon five cast-iron wedging cribs. At 203 yards a sixth crib was put in and a seventh at the bottom, and the whole depth below the fifth crib (63 yards) was lined with cast-iron tubbing to keep back a strong feeder of water at the level of the second or Veronica seam. The tubbing is in eighty-seven rings, each 24·4 inches high, and cast in eight segments; the thickness of the metal is about 1 inch (25 millimètres), and it is capable of resisting a pressure of 787 feet of water. The total weight of metal in the two sets of tubbing, including cribs, valves and

Digitized by Google

relief pipes, is 341·75 tons (metrical), which was built into position in eighty-seven days. The average cost per running yard of tubbing was about £52 4*s.* 6*d.*, or about four times as much as walling with two rings of brickwork, including the necessary cast-iron cribs. The walling has been carried out in hard-burnt (clinker) bricks of a segmental shape, which possess considerable advantages over the ordinary rectangular bricks used at first. The sinking of No. II. pit, begun in February 1870, was, like the former, stopped by the war, and was resumed in 1871, the Veronica seam being reached at 145 yards at the end of 1873. In October 1874 the American method of sinking with the diamond boring machine was adopted, and it is intended to carry the shaft 260 feet deeper, when a cross cut will be driven to No. I. pit. The water from the latter will then be lifted to the surface by a 16-inch lift in No. II., attached to the permanent winding engines, so that the sinking of No. I. may be continued without interruption to the deep seam, which is expected to be reached at 460 yards, the sinking lift having only to pump from a depth of 219 yards.

The permanent winding engines at No I. pit are a pair of horizontal direct-acting construction, about 250 HP., having cylinders 37 inches in diameter and 6 feet 2 inches stroke, with an average piston speed of 308 feet per minute. During the sinking they are used for driving the pumps. Similar engines are supplied to No. II., and a somewhat smaller pair to No. III. pit, to be used during the sinking for pumping purposes. The sinking pumps, 17·3 inches in diameter, are worked principally by the main drawing engines by sweep rods and bell crank. They are described in detail, but have no special peculiarities, except an arrangement for shifting the clacks when the door-piece is drowned. At first packed pump buckets were used, but as these were worn out in six hours with sandy water, they have been replaced by others with hydraulic leathers, which are found to work from twenty to thirty, or in favourable cases thirty six, days without renewal.

A fixed lift was first put in at 95 yards, but since the completion of the tubbing it has been replaced by a Tangye pump, which takes the water directly from the sinking lift and raises it to the adit. In the highest seam, now laid out for working, a Cameron's special pump is used to force water to the surface, where it is used for feeding the boilers.

The permanent drawing arrangements proposed are two four-tub double-decked cages in No. I. pit, and four similar cages in No. II. pit, the former with wire rope and the latter with rail guides; the total quantity of coals drawn is 1 million tons per annum, or 3,000 tons per day. For supplying steam to the numerous engines above and below ground, thirty-two Cornish boilers of so-called "normal" dimensions (? 50 HP.) will be required.

H. B.

Digitized by Google

Peat as Fuel for Industrial and Domestic Purposes.

By A. LENCAUCHEZ.

(Annales du Génie Civil, vol. xiii., p. 757.)

After considering the peat industries of Picardy and Russia, the Author enters into an examination of the methods of 'getting,' preparing, and employing peat, with special reference to the methods of M. Challeton and of MM. Bocquet and Bénard. The peat is dug by mechanical means, or dredged by steam dredgers in the case of submerged peat workings; it is passed through disintegrating mills, on to natural peat-depositing or filtering beds in Challeton's process, and into settling tanks or drying floors in Bocquet's process. The sand is separated by deposition; the twigs are retained, and after drying are used under the boiler supplying steam to the works. When the pulp has attained sufficient consistency, it is moulded by machine or by hand into briquettes, which are stacked till dry. The Author's calculations show that the calorific value as fuel of the best peat so treated is only from 0·5 to 0·75 that of coal of average quality. It is pointed out, however, that a charcoal may be made from it which can advantageously compete with wood charcoal for furnace and metallurgical purposes. The Author then enters into analyses of peat, of the products of carbonisation and sub-products of distillation, and arrives at the conclusion that the most profitable use of peat is as a gas-producing material, particularly as applied for heating purposes; and that the resulting ammoniacal liquors afford a rich supply of ammonia and of sulphate of ammonia for agriculture.

W. W. B.

On the Use of Pulverised Fuel.[1] By B. F. ISHERWOOD, U.S. Navy.

(Engineering and Mining Journal (New York), vol. xxi., pp. 12–130.)

The experiments described were made by a Board of Naval Engineers, in conformity with instructions by the Author, for ascertaining the economic value of burning pulverised coal mixed with air blown into the furnace of a steam boiler above a bed of incandescent coal, compared with burning lump coal alone in the usual manner. It is assumed that the ordinary combustion of lump coal is imperfect, for want of sufficiently intimate mixture of the particles of fuel and of the oxygen of the air, in consequence of which the gases of combustion escaping from the chimney are largely composed of carbonic oxide and hydrocarbons, whilst the quantity of air is greatly in excess of that chemically required, and the furnace temperature is reduced. The process of Messrs. Whelpley and Storer consists in burning as small a quantity of lump coal as can be

[1] *Vide* "Institute of Mechanical Engineers, Proceedings, 1874," p. 141, as to the economy resulting from the use of pulverised fuel.

Digitized by Google

kept incandescent. Air is supplied below the fire-bars by a fan-blast, and is regulated to the exact quantity required for combustion above the incandescent fuel. The pulverised coal is driven in by another fan-blast, and it is recommended that it should be used in as large a quantity as can be properly consumed. When the pulverised fuel was employed, a brick arch was turned over the fire-bars for a length of 3 feet; when not employed, this arch was removed. The experiments were made with Pennsylvania anthracite and with semi-bituminous coal from the Cumberland mines of Maryland, both of the best quality. Of five experiments with each kind, two were made at the maximum rate that could be obtained without too great a sacrifice of the economic results, and three at the rate of about 12 lbs. of coal per square foot of grate surface per hour, including both pulverised and lump coal. All the steam generated, except that used in a small engine which worked the coal-pulverising machine, was blown off into the atmosphere.

The facts determined for the experimental boiler and conditions are—

1. The relative economic value of the anthracite and semi-bituminous coals consumed wholly in the lump state at equal rates of combustion.—It was found that 12 lbs. of anthracite per square foot of grate per hour evaporated 8·654 lbs. of water at 212° per hour at atmospheric pressure, and that under the same conditions the semi-bituminous coal evaporated 9·857 lbs., which gives the value of the combustible matter of the bituminous coal as 13·90 per cent. greater than that of the anthracite. In the second experiment, burning 15 lbs. of each kind of coal per square foot of grate surface per hour, the anthracite evaporated 7·673 lbs. and the semi-bituminous 9·53 lbs. of water, each at a temperature of 212° at atmospheric pressure, giving the value of the pound of combustible in the latter coal as 24·2 per cent. greater than that of the anthracite, and showing that the value of the semi-bituminous coal was relatively greater than the anthracite with the higher rate of combustion than with the lower rate.

2. The relative economic value of the same coals consumed partly in the lump and partly in the pulverised state, also at equal rates of combustion.—Here it was found that the anthracite, burned at the rate of 12 lbs. per hour per square foot of grate surface, evaporated per pound of its combustible matter 7·498 lbs. of water at 212° and at atmospheric pressure; and that the semi-bituminous coal evaporated under the same conditions 10·371 lbs. of water, showing that the value of the latter coal was 38·31 per cent. greater that the anthracite. Again, while burning the same coal at the rate of nearly 16 lbs. per hour, and otherwise under the same conditions as before, the anthracite evaporated 7·206 lbs. and the semi-bituminous 8·755 lbs. of water, giving the value of the latter as 21·50 per cent. greater than the former, and showing that it was less relatively at the higher rates of combustion, which is the reverse of the corresponding experiments with lump coal alone. The mean of all the determinations gave the economic value of 1 lb. of the

Digitized by Google

combustible portion of the semi-bituminous coal as 24·48 per cent. greater than that of the anthracite; but it is noticed that this result is due to abnormal conditions operating strongly against the anthracite, probably the smallness of the grate surface, which made the lump anthracite relatively larger than usual, and which allowed a larger portion of air to pass unconsumed than in the case of the smaller lumps of semi-bituminous coal.

3. The proportion of the total weight of anthracite and semi-bituminous coal, which could be consumed in the pulverised state, was for the anthracite 33 per cent., and for the semi-bituminous 60 per cent., leaving respectively 67 and 40 per cent. as consumed in the lump state on the grate.

4. The relative value of anthracite consumed wholly in the lump, or partly in the lump and partly in the pulverised state.—From the mean of four experiments it appears that the use of 33 per cent. in the pulverised state causes a loss of 9·93 of its economic value when used wholly in the lump state.

5. The relative economic value of the semi-bituminous coal consumed wholly in the lump, or partly in the lump and partly in the pulverised state.—The mean of four experiments, viz., one at 12 lbs. and one at 15 lbs. per hour per foot of grate, in the lump state, and one at 12 lbs. and one at 16 lbs. per hour in the pulverised and lump states in the proportions respectively of 60 and 40 per cent., showed a loss of 1·34 per cent. due to the use of the above percentage of pulverised coal as compared with the same coal burned wholly in the lump state.

6. The relative economic value of anthracite, both in the lump and in the pulverised state, when burned at the maximum rate and at about 12 lbs. per hour per foot of grate.—When using lump anthracite alone, an increase of 29·88 per cent. in the rate of its combustion diminished its value 11·33 per cent., and when using 33 per cent. in the pulverised state an increase of 26·09 per cent. in the rate of its combustion lessened its value 3·89 per cent.

7. The relative value of semi-bituminous coal, both in the lump and in the pulverised state.—When using this coal in the lump state alone an increase of 22·28 per cent. in the rate of its combustion diminished its economic value 3·32 per cent., and when using 60 per cent. of the same coal in the pulverised state an increase of 26 per cent. in the rate of its combustion lessened its value 15·58 per cent. Taking the mean of all the determinations, it appears that by increasing the rate of combustion from 10·418 to 13·782 lbs. per hour per foot of grate, or 32·29 per cent., its value diminished from 9·095 lbs. of water evaporated to 8·291 lbs., or 8·84 per cent.

8. The relative economic value of lump anthracite burned with as little air as practicable, and with the quantity of air which gave the highest evaporative effect.—Experiments under this head showed that burning anthracite under the first condition gave 12·40 per cent. less value than burning it under the latter.

9. Economic efficiency of anthracite burned in the pulverised state.—This was not determined directly, but the experiments fur-

Digitized by Google

nished the data upon which it could be calculated. The mean of two determinations showed that pulverised anthracite, burned under the experimental conditions, gave a result 30·02 per cent. less economically efficient than lump anthracite for the generation of steam in boilers.

10. Economic efficiency of semi-bituminous coal burned in the pulverised state.—When burned at the minimum rate the economic efficiency was 8·84 per cent. greater, and when consumed at the maximum rate it was 13·19 per cent. less, than when lump coal alone was used, the mean result being that the pulverised coal was 2·17 per cent. less efficient than lump coal for the generation of steam in boilers. The anthracite coal gave of refuse in the form of ash, clinker, and soot, 12·87 per cent.; the semi-bituminous coal gave 9·27 per cent.

None of the above values take into consideration the cost of pulverising the coal. When the reductions for this were made the anthracite was found to be 40·81 per cent. less commercially efficient when burned in the pulverised, than in the lump state, and the pulverised semi-bituminous coal was found to be 8·33 per cent. less efficient than similar coal burned in the lump state.

W. W. B.

On the Study of Thermic Motors, and on certain points of the Theory of Heat in general. By G. A. Hirn.

(Comptes rendus de l'Académie des Sciences, vol. lxxxii., p. 52.)

This is an abstract of the second volume of the Author's "Thermodynamique." Book IV. refers to heat engines, and shows, on the one hand, the application and verification of the fundamental equations of the theory of heat, and the impossibility, on the other hand, of discovering from them the particular action of any special engine. In other words, each engine requires special study, and varies in its working at different times from apparently insignificant causes. It is impossible, for instance, to state in advance what quantity of vapour will condense in a cylinder during admission, according to what law it will expand, or what quantity of heat it will give to the walls during condensation—all data necessary to a true theory.

"The fundamental equations of thermodynamics, relatively to vapours, liquids and solids, can be divided into two quite distinct classes. In the one, the internal work—the molecular work—is treated, implicitly or explicitly, as a simple factor. In the other, this work is decomposed into its various elements. To be precise, one example among many is cited. When a liquid boils under constant pressure, and therefore at a constant temperature, it is necessary, in order to evaporate a unit of weight, to employ a certain quantity of heat r, of which the experiments of M. Regnault allow the determination in a large number of cases; this

Digitized by Google

heat, hitherto called latent,[1] represents work, formed of two portions; the one, f, expressing the internal work generated by the vapour in its formation; the other, ρ, expressing the internal work arising from molecular action. Then, in the equations of the first class, the terms r or ρ, and their differentials dr or $d\rho$, remain intact; whilst in those of the second, ρ on the contrary is decomposed into its two factors R and v, the first representing a resistance overcome, whatever its species or origin; the second representing a space traversed, whatever its nature. It is the whole of the equations of this second class, which constitutes what the Author has called the second branch of thermodynamics, retaining the name of first branch for the collection (much more generally known) of the equations of the first class, and the phenomena they concern.

"In examining carefully the causes which disturb certain of the long-known laws of physics, and which have only been considered applicable to a certain limited class of cases, one succeeds, without any gratuitous supposition as to the nature of forces, in giving to these laws a rational and altogether general character, from which is banished all appearance of empiricism. It is thus, for example, that the law of Mariotte and Gay-Lussac, which, as it stands, is not even applicable to gases (Regnault), can, by the help of certain new terms, be converted into a universal law, applying not only to gases and vapours, but also to liquids and solids. These laws, thus corrected and generalised, are only approximate in their new applications; but the causes of perturbations can be easily distinguished, and one sees in what manner they can be more thoroughly corrected.

"The equations of the second branch have not perhaps yet the precision of those of the first, but they are invested, if possible, with a more original and impressive character. They have already enabled us to estimate, in certain cases very correctly, the intensity of molecular attraction; they will soon enable us to weigh the energy of elective affinity. We thus perceive, in an horizon, doubtless still distant, but of a clear and defined form, the origin of mathematical chemistry."

The Author concludes by stating that he has made every effort to keep within the limits of what is either demonstrable or demonstrated; he has formulated certain definitions and propositions, to which he would direct the attention of physicists, and which to him appear to differ from those generally admitted.

E. B.

M. Hirn's Method of Testing Steam-Engines, and its Application.

By F. L. POUPARDIN.

(Bulletin de la Société Industrielle de Mulhouse, 1875, p. 385.)

This Paper is a résumé of the results of M. Hirn's investigations into the action and performance of steam in the Woolf engine, and

[1] Both Rankine and Clerk Maxwell have objected to this expression.—E. B.

Digitized by Google

in the single-cylinder engine, in relation with the conclusions of M. Hallauer and M. G. Leloutre.[1] According to M. Hirn's method of investigation, first described and published by him in 1855, the engine under trial is connected with another engine, or with a hydraulic motor, in order that by its co-operation the work of the establishment may be regularly performed, under all variations of load, and that the trial engine may be maintained at work under perfectly uniform conditions. Each trial lasts for a whole day, for which the distribution of the steam and other conditions are arranged once for all before the commencement of the trial; at the same time, the steam is maintained at a constant pressure in the boiler. The trials are made with different pressures and with different degrees of expansion. After this series of trials is completed a second is made, to gauge, by the friction-brake and the indicator, the performance of the steam in the engine, the conditions under which the first series is made being exactly repeated; but the duration of each trial is limited to sufficient time to enable the observer to satisfy himself that the conditions are exactly the same as before. The number of revolutions is registered by a counter, and the weight of water supplied to the boiler is measured. M. Hirn applies, also, a 'deflection-pandynamometre' to beam-engines, by which the pressures are measured direct from the pistons, exterior to the cylinders, and the indicator diagrams are verified: showing, of course, a slight difference of pressure due to the friction of the pistons. Lastly, he gauges the quantity, together with the initial and final temperatures, of the water discharged from the condenser.[2]

In a Woolf engine, worked with steam of 3·75 atmospheres, M. Hirn found that, for equal rates of consumption of steam, 104 HP. were developed when steam was admitted into the jackets, and 79·5 HP. when the steam was shut off from the jackets, and admitted direct into the first cylinder: showing a gain of 23·5 per cent. of efficiency by the use of the jacket. The Author states, that he proved that a Woolf engine, steam-jacketed, consumed 24 per cent. less steam than an unjacketed single-cylinder engine: a result which indirectly corroborates the deductions of M. Hirn.

In M. Hirn's experiments it was observed that 5·6 per cent. of the steam consumed was deposited as water in the jacket, and that 5·6 per cent. of the water in the boiler passed over as priming with the steam. This coincidence has been much commented upon. According to the observations of M. Hallauer on other engines, the steam contained 6·56 per cent. of water before entering the jacket, and 9·88 per cent. afterwards.

It was shown by M. Hirn that the beneficial influence of the

---

[1] M. Hallauer's experiments have been noticed in the Minutes of Proceedings Inst. C.E., vol. xlii., p. 330.

[2] The method of testing steam-engines by measurement of the condenser-water is the same as that employed by Messrs. W. B. Farey and B. Donkin, jun.—D. K. C.

Digitized by Google

jacket is not due to superheating the steam in the cylinder. The gain of efficiency by this cannot exceed 6·6 per cent., proving that it is due chiefly to the prevention of condensation. M. Hirn found that when the jacket was not in action, the pressure fell from 3·75 atmospheres in the first cylinder to 1·62 atmosphere on entering the second, though, by the inverse ratio of the spaces occupied, the pressure should have been lowered to only 3·11 atmospheres. When the jacket was in action, the pressure only fell to 2·20 atmospheres. Two remarkable facts were observed: when the jacket had been in use for some time, the steam was suddenly cut off, the engine continued to work without any change in the diagram or in the performance, and it was only after from ten to twenty minutes that the power was reduced 23½ per cent. Secondly, the steam was exhausted into the condenser at a temperature of 147° Fahr. and a pressure of 2·95 inches of mercury, when the jacket was in action, and at 136° Fahr., with a pressure of 3·74 inches, when out of action. Again, the final pressure in the second cylinder was 12 lbs. above zero per square inch with steam in the jacket, and 10·2 lbs. without it.

M. Hallauer, experimenting on the Woolf engine of MM. Dollfus-Mieg and Co., found that when steam was admitted to the first cylinder for the whole of the stroke, 23·10 per cent. of the steam was condensed at the end of the admission; 38·37 per cent. at the beginning of the stroke of the second cylinder; and only 11·56 per cent. at the end of the stroke: proving, what is now well understood, that there was a final evaporation of (23·10 − 11·56 =) 11·54 per cent. during the expansion from the first into the second cylinder, due to the combined action of the jacket and of the walls of the first cylinder, which had been heated by the primary condensation of 23·10 per cent. The residual 11·54 per cent. is partly deposited on the surface of the cylinder and partly suspended in the steam, and the deposited water is almost wholly evaporated when communication is opened to the condenser. The method of calculating the exact quantity evaporated has been determined by M. Hirn, with the aid of the principle based on the mechanical equivalent of heat:—that the internal heat of a mixture of steam and water remains unchanged in quantity when heat is neither added nor subtracted externally, and when, in expansion, no work is performed by the mixture.[1] It follows that, when work is done by expansion, the difference of the internal heats, initial and final, at the beginning and at the end of the expansion, plus the heat communicated from without, ought to be equal in quantity to the heat which disappears and is converted into work during expansion. If there be no abstraction of heat by the action of the condenser, the heat to be supplied externally to the cylinder is just what is necessary for the performance of the work.

[1] See a Paper by Dr. Siemens on "The Conversion of Heat into Mechanical Effect," Minutes of Proceedings Inst. C.E., vol. xii., p. 571. In this paper the mechanical theory of heat was first brought before the Institution.—D. K. C.

Digitized by Google

But if the heat externally supplied is greater than that converted into work, plus the augmentation of internal heat, the difference is heat conveyed by evaporation into the condenser.[1]

There are, then, two series of quantities to be equated:—First, the heat absorbed, consisting of the difference of the initial and final quantities of heat in the expanded steam, the heat converted into work by expansion, and the heat abstracted by the condenser. Secondly, the heat given to the surfaces of the cylinders by the steam condensed in the cylinder during the admission, and by the steam condensed in the jackets. Hence the quantity of heat abstracted by the condenser is determined when the other quantities are known. To verify this the heat removed in the condensing water is measured. It consists of the heat of the steam and water discharged from the second cylinder, and the heat of the vapour generated in the second cylinder after it is opened to the condenser and abstracted by it; whence, this second quantity may be ascertained. These independent determinations of the heat so abstracted, or "radiated into the condenser," as made by M. Hirn, were identical within $\frac{1}{2}$ per cent.; and they proved a loss, by this cause, of 33·14 C. units, against 54·84 C. units utilised as work.

The loss by friction of the Woolf engine was determined by M. Hirn to be equal to 10 per cent. of the total work done. The frictional resistance was increased, but slowly, with the load. In the Woolf engine under consideration the increase was 1·89 HP.

M. Hirn, in one experiment in the Woolf engine, in superheating the steam to 410° Fahr., made an economy of 20 per cent. as compared with saturated steam. In a single-cylinder engine, unjacketed, superheating 437°, an economy of 31 per cent. was made, when one indicator HP. was performed by 21·2 lbs. of steam per hour; and by superheating 473° Fahr., the economy was 47 per cent.

M. Hirn's investigations on the evaporation of vesicular water, on the expansion of steam by superheating it, and on the modification of the law of expansion by superheating the steam, are noticed, and a list of the publications referred to in the article is appended.

D. K. C.

Résumé of M. Hirn's new Work on the Mechanical Theory of Heat. By O. Hallauer.

(Bulletin de la Société Industrielle de Mulhouse, 1875, p. 433.)

The substance of this résumé is partly anticipated by the preceding notice of the results of M. Hirn's labours; and attention is now directed to that portion of the work which describes M. Hirn's

---

[1] There is apparently a confusion of ideas in this exposition. In the first case, the final heat after expansion is supposed to be *less* than the initial heat; in the second case, the initial heat is supposed to be less. The exposition is explained by what follows.—D. K. C.

Digitized by Google

researches for the purpose of determining the mechanical equivalent of heat. These consisted of four series of investigations:—

1. On the friction of water.
2. On the flow of water under high pressures.
3. On the crushing of lead under a ram.
4. On the fall of temperature due to the expansion of air.

With respect to the friction of water, M. Hirn employed two concentric cylinders having an annular interval of $\frac{1}{8}$ inch between them, turned and polished on their surfaces. The ends were closed by discs, through which the axle of the smaller cylinder passed in stuffing boxes. The interval between the cylinders was filled with several different liquids, and the inner cylinder was driven at rates of speed varying from sixty to six hundred revolutions per minute. A continuous current of the liquid experimented with was passed through vertical tubes soldered to the lateral discs, the temperatures on entering and on leaving the apparatus being measured. When the inner cylinder revolved it dragged the liquid with it by the friction of its surface, which tended to drag the outer cylinder likewise. But the latter cylinder was maintained in equilibrium by balance-weights on levers fixed on the ends of it. The friction of the stuffing boxes was determined separately, by slowly turning the cylinder without any liquid. This apparatus was worked up to a rate of expenditure of 10 HP. or more; and the results afforded by it were satisfactory, for with different velocities, and different liquids, they gave, within 5 per cent. of deviation, an average of 432 kilogrammètres of work expended for one French unit of heat; equivalent to 787·4 foot-lbs. per English unit of heat.

For experimenting on the flow of water under high pressures, a gun-metal pump was placed in a reservoir of water; a copper tube was fixed to the escape-valve box, terminated with a slender glass tube having an orifice of $\frac{1}{2}$ millimètre, or $\frac{1}{50}$ inch in diameter. A bar of iron, resting at one end on a knife-edge, and at the other end on the piston-rod, thus exerted on the water a pressure of 645 lbs. per square inch. The liquid from the pump escaped through the glass tube, and for each degree of temperature by which it was elevated, 433 kilogrammètres of work were expended per kilogramme of water; equivalent to 789·2 foot-lbs. per English unit of heat.

From the elevation of temperature of pieces of lead subjected to the blow of a ram of 770 lbs. weight, falling freely through a given height, it was calculated, as the result of six experiments, that 425 kilogrammètres were expended for each unit of heat developed; equivalent to 774·6 foot-lbs. per English unit.

From experiments on the expansion of gas, compressed in a reservoir and permitted to escape, M. Hirn found, as an average result of forty experiments, that the mechanical equivalent of one calorie was 441·6 kilogrammètres; equivalent to 805 foot-lbs. per English heat unit.

On the evidence as a whole, M. Hirn concludes that the most nearly correct value of the equivalent is 432 kilogrammètres per

Digitized by Google

calorie; or, in English measures, 787·4 foot-lbs. per heat unit. At the same time he retains for use the value, 425 kilogrammètres per calorie, which has been adopted by most Authors on the theory of the mechanical equivalent of heat.

A full table, originally published by the Physical Society of Berlin, of the various values assigned by experimentalists to the mechanical equivalent of heat, is given by M. Hirn.

D. K. C.

Theory of Superfusion and Supersaturation, after the Principles of the Mechanical Theory of Heat. By M. DE COPPET.

(Annales de Chimie et de Physique, 5th ser., vol. vi., p. 275.)

The Author defines the spontaneous crystallisation of supersaturated solutions as crystallisation in a hermetically closed vessel, free from dust, and not containing an already formed crystal. In a former memoir[1] it was stated, as the result of experiment, that there is no fixed temperature at which spontaneous crystallisation necessarily occurs. Herr Clausius is quoted in support of the theory that heat in solids is vibratory motion only, extending to fixed positions of equilibrium in liquids; the molecules are not fixed, but glide over one another without breaking up, whilst in gases the molecules move according to the ordinary laws of motion. Following M. Dossois, let A be a molecule at the surface of a solid in contact with a liquid, whose molecules are represented by B. Molecules A may move in the direction of the liquid; becoming liquid, they move among the B molecules, some re-attaching themselves to the solid. After a time, there will be a moment when, during a given interval, the number of liquid molecules A, which return to the solid state, is sensibly equal to that of the solid molecules detached through the influence of B; the liquid is then supersaturated with the solid A. Solubility increases with rise of temperature, as the latter means an increase in the intensity of the molecular movements.

If a crystallisable liquid is cooled near to its point of solidification, and if it contains a crystal of the same substance, the liquid molecules will attach themselves to the solid crystal; whereas, if no crystal be present, the liquid may remain in that state within certain limits of temperature for an indefinite period, as it will require a simultaneous and special direction of motion for the production of the first crystal. The same holds with regard to a supersaturated solution. The Author draws the following conclusions, the first agreeing with universal experience, and the second with his own experiments. 1st. The mean time necessary for the spontaneous crystallisation of a liquid in the state of super-

[1] Bulletin de la Société Chimique de Paris, 1872, vol. xvii., p 146.

Digitized by Google

fusion, or of a supersaturated solution, ought to be less as the temperature is lower, and for a supersaturated solution ought to be less as the solution is more concentrated. 2nd. The mean time should be inversely proportional to the mass of the body melted, or of the supersaturated solution. These conclusions must be restricted to cases where there is no special chemical modification of the substance.

E. B.

On the Laws of Gases. By D. MENDÉLÉEFF.

(Comptes rendus de l'Académie des Sciences, vol. lxxxii., p. 412.)

Mariotte's law, Gay-Lussac's law, and the law given by Ampère and Avogadro may be expressed, as a whole, by the equation

$$a\,p\,v = \mathrm{K}\,(\mathrm{C}+t)\,m \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where a is the weight of a chemical molecule (hydrogen being taken $=1$) which for hydrogen gives $a=2$, for nitrogen $a=28$, and for air the molecular mean weight is 28·84; p is the pressure per square mètre, in kilogrammes; the normal pressure is 10,333; m is the weight of the gas in kilogrammes; v its volume in cubic mètres; $\frac{m}{v}=\Delta$ the weight of 1 cubic mètre of the gas. Introducing this notation in equation (1) the more general form

$$\frac{a\,p}{\Delta} = \mathrm{K}\,(\mathrm{C}+t). \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

is obtained. t is the temperature in degrees centigrade; C is a constant $=\frac{1}{a}$ differing little from 272; K is a constant very nearly equal to 845—its expression is $\mathrm{K} = (c'-c)\,a\,\mathrm{E}$, E being the mechanical equivalent of heat ($=424$); c' and c represent the specific heats of the two gases (thus for air, $c' = 0{\cdot}2376$, and $c = 0{\cdot}1685$). As $(c'-c)\,a$ is for all gases but little different from 2, the quantity K is approximately equal to 2 E.

According to Clapeyron, laws (1) and (2) are expressed by the equation

$$p\,v = \mathrm{R}\,(\mathrm{C}+t) \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The constant R varies with the nature of the gas, whilst the value of K in equation (1) is the same for all gases, as far as they follow the three laws. Formula (1) then furnishes most completely an expression for the properties of gases which are approximately perfect gases. These three laws, however, differ from the law of gravitation, in that they are only a first approximation. To consider as simply as possible the departure relative to these laws observed with gases, it is necessary to regard C and K in formula (1) not as

Digitized by Google

constants, but as functions of the nature of the gas, its temperature, and its pressure. The most important question is whether these two quantities depend upon a, p, and t, or whether this dependence exists for only one of them. Regnault's experiments show that $C = \frac{1}{a}$ depends upon p and a. As the pressure increases a increases, and consequently C diminishes: there is then $C = C_0 (1 - Ap)$. The experiments of Magnus and Joly prove that C depends upon a. For gases, possessing the same molecular weight, and consequently the same specific weight, have the same co-efficient of expansion; and proportionally as the molecular weight a, and consequently the density of the gas, increase, a also increases. The questions relative to the quantities R in equation (3) and K in equation (1) are more complex. Nevertheless, examination leads to the assumption that not only C, but also K (and therefrom R) are functions of the pressure. Experiments by Regnault, Natterer, Cailletet, and the Author tend to show this. It follows that the law of dependence of variations of $p\,v$ with those of p, should be represented by a complex curve. It may be judged from Regnault's data that the variations of C with the variations of pressure may be represented by a nearly straight line. The dependence between C and p will therefore not suffice to explain departures from Mariotte's law. The same conclusion is drawn from comparison of Regnault's observations on the variations of the numbers a and a' (co-efficients of expansion for air at constant volumes and constant pressures) with the variations of the pressures, for the two co-efficients become equal (0·00369) under pressures near 2·50 mètres (98·2 inches). Finally, the Author deduces that the relation (1) which exists between the fundamental properties of a gas should be replaced, in order to have a second approximation, at least by an expression of the form

$$\frac{a\,p\,v}{m} = (K_0 + A'p + B'a)\,(C_0 + t - Ap - Ba).$$

Ulterior researches will determine the values of A, B, A', B'. The Author commenced such researches in 1872, and has published the first part, having in view chiefly the departures from Mariotte's law for gases under different pressures, and the determination of the co-efficient of expansion under constant pressures.

P. H.

On the Co-efficient for Expansion of Air under Atmospheric Pressure. By D. MENDÉLÉEFF and N. KAIANDER.

(Comptes rendus de l'Académie des Sciences, vol. lxxxii., p. 450.)

The Authors consider that the number 0·3665, which has been obtained by M. Regnault in measuring the variations of pressure between zero and 100° cent., is affected by departures from Mariotte's

Digitized by Google

law; and they describe a process of determining the co-efficient which is applicable under all pressures, and can also be used for liquids. α being the co-efficient for the expansion of air, the following are the results of nine experiments at the barometric pressure B (in millimètres) and the temperature T (in degrees centigrade):—(B is barometric pressure at zero, corrected with regard to the tension of the air in the vacuum. The correction determined by experiment varied between +0·7 millimètre and +0·4 millimètre.)

B.	T.	$100\,\alpha$
767·4	100·27	0·36824
767·6	100·28	0·36876
770·1	100·37	0·36866
768·9	100·33	0·36849
766·4	100·24	0·36845
767·3	100·27	0·36843
759·5	99·98	0·36850
772·6	100·46	0·36814
749·7	99·62	0·36820

From these data it follows: (1) that for the pressures of 750 millimètres to 770 millimètres, the co-efficient of expansion for air is $\alpha = 0{\cdot}0036843$, or that a volume of 1·00000 at zero occupies at 100° a volume of 1·36843; (2) that the probable error from the mean of α is $\pm$ 0·0000005, and the probable error of a single observation is $\pm$ 0·0000014, and taking the maxima possible errors of the weighings, temperature, of the determination of the variation of capacity for 1° cent. of the vessel used, there is a possible maximum error for α in a single determination of 0·0000016. The accordance between the possible error and the probable error leads the Authors to the conclusion that new determinations, having the same degree of precision, will give for α a mean between the limits 0·003686 and 0·003683; as the most probable number this is $\alpha = 0{\cdot}0036843$, or about $\frac{1}{2\,7\,1\,5}$ in place of $\frac{1}{3\,0\,0\,0}$ hitherto adopted.

P. H.

On the Specific Heat of Gases. By E. WIEDEMANN.

(Poggendorff's Annalen der Physik und Chemie, Bd. clvii., p. 1.)

The Author seeks to verify and extend Regnault's researches, and describes in the first part of the Paper a new method of determination and the apparatus employed. His results are given in the following table: the first, second, and third columns show the specific heat of the gas at 0°, 100° and 200° cent., relatively to the unit of weight; the fourth gives the difference of the specific heats at 0° and 200°, expressed in percentages of the specific heat at 0°. The fifth, sixth, and seventh columns show the specific heat relatively to the unit volume, the specific heat of the unit-volume of air being equal to 0·2389. The eighth column shows the specific weight of the gas; and the ninth gives Regnault's ratio of the pro-

Digitized by Google

duct of the volumes V and V_1, into the pressures P and P_1, where P is 1 atmosphere, and P_1 is 2 atmospheres. The variation of this number from unity, which represents a perfect gas, serves as a measure of the variation from perfect gaseous condition.

SPECIFIC HEAT WITH EQUAL WEIGHT.

	I. 0°	II. 100°	III. 200°	IV.
Air	0·2389	..	..	0
Hydrogen	3·4100	..	..	0
Carbonic oxide	0·2426	..	..	0
Carbonic acid	0·1952	0·2169	0·2387	22·28
Ethylene	0·3364	0·4189	0·5015	49·08
Nitrogen protoxide	0·1983	0·2212	0·2442	23·15
Ammonia	0·5009	0·5317	0·5629	12·38

SPECIFIC HEAT WITH EQUAL VOLUME.

	V. 0°	VI. 100°	VII. 200°	VIII. Sp. gr.	IX. $\frac{PV}{P_1V_1}$.
Air	0·2389	..	..	1	1·00215
Hydrogen	0·2359	..	..	0·0692	..
Carbonic oxide	0·2346	..	..	0·9670	1·00293
Carbonic acid	0·2985	0·3316	0·3650	1·5290	1·00722
Ethylene	0·3254	0·4052	0·4851	0·9677	..
Nitrogen protoxide	0·3014	0·3362	0·3712	1·5241	1·00651
Ammonia	0·2952	0·3134	0·3318	0·5894	1·01881

According to Avogadro's law, that equal volumes of gases contain equal numbers of molecules, the specific heat of equal volumes is also the molecular heat.

P. H.

The Relative Value of Blows and Pressure.

By PROF. F. KICK.

(Dingler's Polytechnisches Journal, vol. ccxvi., p. 377.)

The Author, after mentioning the numerous alterations of form in materials produced by a power, acting either quietly and constantly, or suddenly by blows, alludes to the difference of forging by hammers instead of by the Haswell press forge; of coining with the old stamp and fly press, instead of by Uhlhorn's machine and hydraulic press; to the manufacture of rod iron before the introduction of rolling mills; and to the boring of stone with jumpers, in contrast with the revolving diamond-cutter of the present day; and he proceeds to deduce from the foregoing illustrations, "that a mechanical power, acting by blows, can be advantageously replaced by one acting by pressure; and that the labour expended in shaping materials under a quiet pressure, is less than that required in employing blows."

The word "pressure" is used to denote tension, deflection, crushing, breaking, displacement, or torsion.

The work of shaping—be it stretching, shortening, bending,

Digitized by Google

tearing, breaking, &c.—amounts to bringing the particles of any body—or at least a certain portion of them—into a different relative position. Every movement of a particle, which by an alteration of form must change its relative position, will meet with a certain amount of latent resistance. Supposing exactly the same alteration of form is produced by a quiet pressure and by a blow, the latent resistances are overcome equally in both cases; therefore the amount of work done must also be equal in each, *i.e.*, the mechanical effect, produced by the machine acting by pressure, must be equal to the percussive effect, or 'vis viva,' required of that acting by blows, in producing the like result.

This ideal demand cannot however be fulfilled, because the blow must always produce condensation of the direct impinging and impacted surfaces, as well as vibrations which have nothing to do with the actual intended alteration of form; hence mechanical effect is wasted.

If, for example, a weight is allowed to fall on the centre of a bar of iron supported at both ends, there will follow, not only a deflection of the bar, but also a compression of the outside strata, which come into immediate contact with the blow, and an increase of heat often very perceptible. The mechanical equivalent for one unit of heat being, as is well known, 772 foot-lbs., there results, by a comparatively small increase of temperature, a large loss of effort, and, in consequence of depression caused by the blow, a considerable waste of percussive effect intended for the alteration of form. To this must be added the almost unavoidable vibration of the supports. It is admitted that a blow fulfils an immense duty when a rigid substance has to be divided; and that the splitting of a block of stone in the usual way, with wedges driven in with sledge-hammers, requires a small amount of effort, compared with what would be necessary to separate the block by pressure; but this admits of explanation. By splitting a block with wedges, only those particles which lie in the line of rupture require to be affected to obtain a separation, while the whole block remains unaltered; whereas, if a separation be produced by weight acting by pressure, the effect will not be confined to the line required alone to be affected, but will be attended by expansions and contractions in every particle of the stone, and the greater part would be useless, if not detrimental.

Blows, when applied to alteration of form, suffer a diminution of effect by compression of the outer surfaces, and the conversion of work into heat, to a much greater extent than when a quiet and constant pressure is applied.

The following tables of experiments are ample proof of the lesser expenditure of effort for the same effect by the application of pressure instead of blows.

Trial I.

In a lecture on steel bronze, on the 10th of April, 1874, General Uchatius, the inventor of the new Austrian field-piece, published

Digitized by Google

the results of his trials of the tensile resistance of cast iron for cannon to blows and strains.

The length of rod was 2·95 inches; sectional area, 0·0775 square inch; weight of monkey, 2·53 lbs.

	Inches.				Foot-lbs.
The rods were torn asunder with	28·35	fall with	1	blow producing	6·0
" " "	24·8	"	2	blows "	10·3
" " "	21·3	"	4	" "	17·9
" " "	17·7	"	8	" "	29·9
" " "	14·2	"	14	" "	42·0
" " "	10·6	"	37	" "	83·1
" " "	7·0	"	352	" "	527·0
" " "	3·5	"	2,052	" "	1,586·2

Consequently a rupture was effected with the least expenditure of effort with a fall of 28·35 inches, viz., 6 foot-lbs.

An alteration of form is therefore obtained by strokes or blows, with so much less expenditure of effort, as the number and strength of the blows applied are fewer and stronger.

The trials, made to ascertain the amount of labour required to tear asunder the same materials by a continuous strain, gave the following results:—

Weight in Tons per Square Inch.	Extension in 0·00001 of Length.		Weight in Tons per Square Inch.	Extension in 0·00001 of Length.	
	Elastic.	Permanent.		Elastic.	Permanent.
0·63	2	7	8·25	84	14
1·27	10	0	8·89	92	19
1·90	15	0	9·52	101	24
2·54	22	0	10·16	110	30
3·17	27	0	10·79	120	35
3·81	33	0	11·43	130	50
4·44	38	2	12·06	142	65
5·08	47	4	12·70	157	81
5·71	54	5	13·33	..	..
6·35	61	6	13·97	..	..
6·98	68	8	14·60	..	..
7·62	76	10	15·36	Rupture.	

These results are set forth in a diagram, in which the abscissæ represent the weight, and the ordinates the total extension, which shows that the effective labour required for tearing asunder a rod of cast iron, with sectional area of 1 square centimètre, as compared with the amount required for the same purpose by blows, gives a result in favour of pressure of 8 to 1.

The work by pressure required for extension up to the limit of elasticity, with a sectional area of 0·0775 square inch, is about 0·022 foot-lb., equivalent to a blow of 2·53 lbs. falling from a height of 0·118 inch; whereas Uchatius found that, by using blows of the same weight with a fall of 1·18 inch, the limit of elasticity was not exceeded.

Digitized by Google

Since this experiment shows that one strong blow is more efficacious than many weaker blows, and that an equal effect is obtained, with a less expenditure of labour, by a quiet and constant pressure, it follows that, as regards cast iron, blows are attended by a greater waste of power than pressure in performing the same work.

Trial II.

To prove the theory as regards wrought iron, Mr. Robert Lane Haswell, of Vienna (see next Abstract), made two comparative trials, viz., to bend an axle by quiet continuous pressure, and to straighten the same by blows. If the permanent deflection be not great, the expenditure of labour necessary to straighten it can be considered equal to that required to bend it; because the same blow ($W \times H$) which had previously caused a certain deflection was sufficient, when properly applied, to straighten the bent axle.

The weight of lever and scale amounted to 530·75 lbs.; and as the short arm was 8·268 inches, and the long arm 190·75 inches, the transmission was $\frac{190 \cdot 750}{8 \cdot 268}$ inches, or 23·07. The distance between the underlying blocks was 4·9 feet. The trial with a wrought-iron axle of 5·25 inches diameter gave the following results:—

Weight applied in cwts. to Lever.	Deflection in Millimètres.		Remarks.
	Elastic.	Permanent.	
4·92	2·70	0	
5·90	3·10	0	
6·89	3·46	0	The weight applied added to 530·75 lbs., and the sum multiplied by 23·07, will give the pressure applied to the centre of the axle.
7·87	4·10	0·46	
8·36	4·60	0·75	
8·86	5·10	1·30	
9·35	6·60	2·60	
12·30	..	17·00	
13·48	..	24·00	

In accordance with the above results, a second diagram gives, by a permanent deflection of 0·945 inch, an expenditure of labour of 904 foot-lbs.; the ordinates again representing the extension, and the abscissæ the load, which must, however, be first multiplied by 23·07.

The same axle was straightened under the blows of a monkey of 12·76 cwt.

Blow.	Height of Stroke in Inches.	Deflection in Millimètres.
1	23·62	12
2	23·62	5
3	13·07	3
4	13·18	2

Digitized by Google

The entire expenditure of labour in straightening the axle (a slight counter-deflection actually taking place) amounted to 8,770·75 foot-lbs.; for straightening a deflection of 0·472 inch, only 2,818·7 foot-lbs. were required.

A second diagram of pressure shows for the deflection from 0·472 inch to 0·945 inch, an expenditure of labour of 260 foot-lbs. Hence the proportion of press work to that of blows is nearly 1 to 7.

In a second trial, a Bessemer steel axle of 5·1 inches diameter, under the same press, was permanently deflected 0·49 inch, as follows:—

Weight in lbs. on Lever.	Deflection in Millimètres.		Weight in lbs. on Lever.	Deflection in Millimètres.	
	Elastic.	Permanent.		Elastic.	Permanent.
55	1·50	..	847	3·99	..
110	2·00	..	1,067	4·99	..
165	2·00	..	1,287	5·66	0·9
297	2·75	..	1,672	7·70	1·5
462	3·20	..	1,947	8·40	3·5
572	3·40	..	2,431	9·30	9·3
627	3·50	..	2,603·7	15·00	12·5

A third diagram, constructed on the above data, shows an expenditure of labour amounting to 1,656 foot-lbs. For straightening the same axle by blows, the following results were obtained:—

Blows.	Height of Fall in Inches.	Deflection in Millimetrès.
1	23·6	7·0
2	27·5	2·5
3	23·6	..

The effective labour here was 649·5 × 1·9 = 1,234 kilogrammes.

By quiet pressure, the deflection between 7 millimètres and 12·5 millimètres required an expenditure of effort = 542 foot-lbs.; while the first blow expended 2,814·5 foot-lbs. In this case, therefore, the pressure compared with blows is nearly as 1 to 5.

From the above the Author draws the following conclusions:—

1. A greater expenditure, or waste of labour, is caused by blows shaping or dividing substances, than if a quiet and constant pressure be applied.
2. If the mechanical effort necessary to separate or break a substance under pressure is known, one blow, exercising the same mechanical power, will not have the same effect.
3. The mechanical power necessary to effect the temporary alteration of a substance, up to its limit of elasticity, if applied through the medium of blows, will not affect that substance up to the limit of its elasticity.

W. E. T.

Digitized by Google

On the Insufficiency of the Tests in use for Steel Axles.

By Robert Lane Haswell.

(Technische Blätter, vol. vii., p. 18.)

Since the introduction of steel axles into Austria, various tests have been prescribed for them by railway engineers, all consisting of blows delivered by a falling weight or monkey, but otherwise differing in every conceivable degree. Experiments made by the Author have brought out in a strong light the unsatisfactory character of all these tests, and the evil results which flow from some of them. They are, however, applied to only from 1 per cent. to 2 per cent. of the whole number.

The test by impact was no doubt chosen as being analogous to the shocks the axle has to bear in actual work; but these are much smaller than the blows of a monkey; and it is their continual repetition which, straining the metal somewhat beyond its elastic limit, gradually weakens and destroys it. Hence the material to be chosen should be that which will resist the greatest number of such blows without injury. Now for such a purpose hard steel has been shown to be much superior to iron or soft steel.[1] On the other hand, soft steel, from its greater ductility, resists the heavy blow of a monkey better than hard steel; and thus the tendency of the present tests is to prevent the use of the metal which would be the best in actual practice. In fact, the steel axles now in use are in many cases actually softer than iron axles. Wöhler considers the tenacity of good steel to be 77 kilogrammes per square millimètre (48·891 tons per square inch); but the tenacity of the present axles is about 30 kilogrammes per square millimètre (19·048 tons per square inch) or even less. Such soft steel is in no way better than iron, while it has the disadvantages of steel, and also runs a risk of being burnt in manufacture.

In the most severe test—that of the Emperor Ferdinand Northern railway—the axles are 5·12 inches in diameter, and the monkey weighs 8 cwt. The distance between the supports is 4 feet 11 inches, and the height of the fall was at first 18 feet 8 inches, increased not less than 2 feet 1 inch after each blow. The test required is that the axle shall be bent backwards and forwards through a distance of 9·3 inches in each direction, until it has sustained at least 500,000 foot-lbs., as calculated by the formula $P \sqrt{2gh}$ (which formula, as remarked by the editor, is not the correct one for impact).

Again, on the Royal-Imperial Southern railway the weight of the monkey and the distance apart of the bearings are the same, but the height of the fall is constant at 14 feet 6 inches, and the axle, which is 4·6 inches in diameter, has to be bent through 9·8 inches,

[1] See Wöhler, "Ueber die Festigkeitsversuche mit Eisen und Stahl." Berlin, 1870.

Digitized by Google

and straightened again by blows on the other side. This test is less severe than the former, and allows of a harder quality of steel; but neither of them, as proved by the Author's experiments, gives a criterion of the excellence of the metal.

In actual use, axles only break from some flaw, as the load is never near enough to the breaking strain to cause danger. Flaws are always liable to occur in a metal such as Bessemer steel; they are due either to oxidised blisters, which refuse to weld (and which are especially common in soft steel), or to crystallisation through over-heating, or to local strains due to repeated heatings and coolings, or to unobserved surface defects. The influence of these is sufficiently shown by experiments made by a committee of the Engineers and Architects' Society of Austria. Two tests were used; the first, equivalent to that of the Emperor Ferdinand Northern railway, but with a heavier monkey, weighing 11·7 cwt.; the second, a series of blows from the same monkey, but at a constant drop of 24 feet 7 inches, the axle being turned after each blow. In all cases the limit of elasticity was first ascertained by an indicator working in a vertical groove, and having a spring which held it in any position within the groove. The monkey (which was steadied by guides) moved this indicator in its rebound; and where with an increased height of drop, the height of the rebound did not increase, the limit of elasticity was considered to be reached. This coincided closely with the point at which permanent set was first observed. From this was deduced the limit of impulsive work which the axle would sustain without permanent set, being the product of the weight of the monkey and the height of fall at the last blow before permanent set was observed; the actual maximum elasticity being, of course, the product of the weight of the monkey and the greatest observed rebound. The limit of elasticity, or 'proof strength,' thus found, was afterwards compared with the ultimate strength, as ascertained by testing the axles to fracture. To measure the deflection, marks were made on both the upper and under sides of the axles, 4 inches from the centre, and the versine of the chord thus formed was measured after each blow. In this way the compression and extension of the extreme fibres could also be ascertained.

In the Northern Railway Company's test the side of one of the axles was first compressed by an amount equal to 13 per cent., then extended by 18·7 per cent. (the axle being turned over and struck on the other side), and lastly, the axle, after being restored to its original position, was compressed by 9·9 per cent. Of sixteen steel axles only three withstood this test successfully: but to prove its absurdity an iron axle with a higher elastic limit endured the test better than any of them; and even an iron axle, confessedly red-short and imperfect, stood it quite as well as many of the steel axles. Again, of two cast-steel axles made from the same ingot, one received five times as much mechanical work before breaking as the other.

Digitized by Google

Under the other test (blows on alternate sides with a constant drop) the behaviour of the axles was much better. Thus, of thirteen axles, the average mechanical work of fracture was 752 foot-lbs.; while for sixteen axles subjected to the Northern Railway Company's test, the average mechanical work of fracture was only 209·2 foot-lbs.

The general principles arrived at are:—

1. That the present system of tests has ended in making steel axles actually softer than iron ones: this is confirmed by the deflections produced under the first blow in each case, which were no greater in the case of iron axles than steel ones, though the former were of smaller dimensions.
2. That no system can be relied on which tests only a small percentage of the total number; since axles made under the same circumstances, and even from the same ingot, may differ widely in quality.
3. That tests requiring a great set, and consequently elongation and compression of the fibres, can only be borne by steel of the softest quality, and that such tests bear no comparison with the strains in actual work.

Hence it follows that none of the existing tests afford any real security for excellence of material. In spite of them, steel axles may probably be running which are inferior in strength and elasticity to wrought iron, whilst they have all the disadvantages of steel. In their place two kinds of tests are proposed. The first consists in subjecting every axle to a test within the limits of elasticity. This would produce a searching inspection of all the axles, and would detect any really faulty ones, such as a specimen which broke while its limit of elasticity was being ascertained. The second test is already used by the Austrian artillery service, and consists of a single blow heavy enough to produce a small permanent set, and therefore extending beyond the limit of elasticity. The amount of this set would determine the quality of the axle. It is true there is a prejudice against subjecting any piece to a strain beyond its elastic limit, but the Author considers this may be carried too far, as where this strain is not excessive, many millions of repetitions would be required to produce actual fracture.

Should such tests not be practicable, the Author's opinion is, that a return should be made to iron as a safer material for axles than Bessemer steel.

W. R. B.

Digitized by Google

The Utilisation of Heat in Furnaces. By M. L. GRUNER.

(Annales des Mines, vol. viii., p. 173.)

A comparison of the useful effect of heat applied with that lost in various kinds of furnaces can only be precisely determined in the case of simple fusion of a metal or of a silicate; as in oxidising operations heat is given off, and in fusions it is absorbed. There are two modes of estimating the heat expended in furnaces: one, by means of the ratio which the heat utilised bears to the total heat that the fuel can develop; the other, by the ratio of the heat utilised to that produced in the furnace itself. In the former case, if the fuel is charcoal or coke, the carbon is directly transformed into carbonic acid, thus developing 8,080 thermal degrees per kilogramme; in the latter case, the carbon becomes carbonic oxide, a combustible, which only gives off heat on combustion and transformation into carbonic acid; thus, in order to ascertain the heat in thermal degrees actually developed in the furnace, the relative quantities of carbonic acid and carbonic oxide existing in the products of combustion must be determined in each case. For instance, in blast furnaces 1 kilogramme of carbon may develop, not 8,080 thermal degrees, but only from 3,854 to 3,245, according to the mode and economy of working adopted; thus showing the error that may arise from not taking into consideration the complex nature of the products of combustion, and from a want of knowledge of the amount and proportions of carbonic acid and carbonic oxide present. This latter can now be easily ascertained by the mode adopted by M. Orsat. The results obtained for furnaces of various kinds show that the blast furnaces and the annular Hoffman furnaces produce the highest useful effect (see p. 311).

These results show that the heat utilised in certain furnaces of this type is only one-third, and never as much as one-half, of the total heat; and that the ratio of the heat utilised to that actually developed in the furnace varies between 0·715 and 0·810: the loss, which thus varies between 20 and 30 per cent., clearly corresponds to the heat carried off by the gases; and as the loss through the walls is nearly constant, it is evident that almost the whole of the heat lost is carried out of the mouth of the furnace by combustible gases. These conclusions are, however, only applicable to calcined ores; in the case of hydrated and carburetted ores the heat thus carried away is far less, and the useful effect correspondingly greater.

The annular furnaces of the Hoffman type produce a useful effect equal to that of the last class. This is probably due to the mixture of the fuel with the substance to be calcined, and to the rigorously methodical arrangements for heating. In burning lime, 13 to 15 lbs. of coal are consumed to 220 lbs. of lime, or 0·06 lb. of coal per lb. of lime; and the heat developed is $8,080 \times 0{\cdot}06 = 485$ caloric units: to drive out the carbonic acid 373 are necessary; hence 77 per cent. must be utilised out of the total heat employed, which,

Digitized by Google

	Names of Furnaces.				
	Small Blast Furnace at the Clarence Works, 1853.	Large Blast Furnace at the Clarence Works, 1866.	Ormesby, 1867.	Consett ordinary Hot Blast.	Consett extra Hot Blast.
Carbon burnt per kilogramme of metal produced	lbs. 2·833	lbs. 2·178	lbs. 2·171	lbs. 2·212	lbs. 1·735
Total heat, when all the carbon is transformed into carbonic acid.	Units. 10,407	Units. 7,999	Units. 7,975	Units. 8,124	Units. 6,375
Heat actually received for combustion and in hot blast . .	4,935	4,418	4,459	4,192	3,654
Heat utilised in the reduction of the ore, fusion of metal and slag, decomposition of lime, &c.	3,548	3,420	3,373	2,997	2,960
Heat carried away by gases .	923	545	646	758	303
Heat lost through the walls .	464	453	440	437	391
Total heat expended equal to that received	4,935	4,418	4,459	4,192	3,654
Ratio of heat utilised to total heat.	0·341	0·427	0·423	0·369	0·464
Ratio of heat utilised to heat actually developed in the furnace.	0·719	0·774	0·757	0·715	0·810

on account of the combustion being smokeless, is equal to the heat actually developed. In burning red brick, 0·77 lb. of coal is consumed per lb. of baked brick, which is an expenditure of 0·035 × 8,080 = 283 units of heat, while the heat utilised corresponding to the evaporation of 0·66 lb. of water requires 637 × 0·30 = 191 units: hence the useful effect in this case is 70 per cent.

The general conclusions drawn from the consideration of furnaces of different types show that the useful effects vary between wide limits, from 3 to 80 per cent. In coke furnaces for melting steel, the metal absorbs only 1·7 per cent. of the total heat that the fuel can develop, and only 3 per cent. of the heat actually developed in the furnace. In reverberatory furnaces, when the steel is cast in crucibles, the corresponding useful effects are 2 per cent. and 3 per cent. In Siemens furnaces with crucibles, the fusion of steel absorbs only 3 to 3·5 per cent. of the total heat. In glass-works, when the pots contain 1,100 to 1,320 lbs. of glass, 3 per cent. of the total heat is utilised in the case of ordinary furnaces, and 5·5 to 6 per cent. in the Siemens furnaces. In smelting on the open hearth of a reverberatory

Digitized by Google

furnace, the useful effect is 7 per cent. for glass and 8 per cent. for iron; but in the more simple process of reheating iron, and copper and silver ores, 6 to 10 per cent. of the heat expended is utilised; though in Ponsard and Siemens furnaces this may reach 15 per cent., and, under exceptionally favourable circumstances, 20 per cent. The useful effect in Bessemer converters and in Deville's furnaces for the fusion of platinum amounts to 11 and even 14 per cent.

The useful effect in the worst cupola is greater than in the best reverberatory furnaces, the lowest of the former utilising 18 to 20 per cent. of the heat expended, or 29 to 30 per cent. of that developed. The old half-blast furnaces of copper-works utilise in corresponding terms 25 per cent., and 40 to 45 per cent; while the modern lofty cupola furnaces utilise more than 50 per cent.

Blast furnaces, according to working, utilise 70 to 80 per cent. of the heat developed, or from 34 to 40 or 50 per cent. of the heat that the coal consumed could develop by perfectly complete combustion; and Hoffman's annular furnaces produce the same amount of useful effect.

L. D'A. J.

On the Temperature of Gas Furnaces. By S. PÉRISSÉ.

(Revue Universelle des Mines, &c., vol. xxxviii., p. 269.)

The manufacture of steel on the hearth of a reverberatory furnace could not have become, as it has done during the last ten years, an important branch of industry, but for the Siemens system of producing high temperatures; and the great economy of combustible is attributed to the comparative rapidity of the heating operation due to the high temperature of the flame. The gas furnaces, with natural draft, of Siemens and of Ponsard, are the only ones capable of producing higher temperatures than other metallurgical furnaces; because all the elements for combustion are gaseous, and of the same density; and they are supplied at a high temperature before combustion.

In calculating the actual temperature developed in gas furnaces the Author uses the researches of M. St. Claire Deville on dissociation, or on the partial decomposition of gaseous products of combustion into their elements, at elevated temperatures, which operates as a hindrance to the completion of combustion. By the ordinary method of calculation the theoretical temperature of combustion is readily determined, in terms of the total heat evolved, and of the weight and specific heat of the gaseous products of the combustion. To make the required correction for the tendency to 'dissociation,' the graphic method of M. Vicaire, for representing the law of the variation of temperature according to the proportion of the combined gases, is adopted; and a résumé of this method is given, with illustrative diagrams.

Digitized by Google

The composition of the gas generated in the Siemens furnace at St. Gobain is, according to M. Kraus, as follows:—

		By Volume.	By Weight.
Carbonic oxide,	CO	24·2	25·56
Hydrogen,	H	8·2	0·62
Hydro-carburets,	C^2H^4	2·2	1·35
Carbonic acid,	CO^2	4·2	7·03
Nitrogen,	N	61·2	65·44
		100·0	100·00

The specific gravity of these gases is 0·92. The composition of the gas generated in the Ponsard furnaces is stated to be generally as follows:—

	By Volume.	By Weight.
Carbonic oxide	22·0	23·20
Hydrogen	9·0	0·94
Hydro-carburets	5·0	4·46
Carbonic acid	5·0	8·37
Nitrogen	59·0	63·03
	100·0	100·00

The specific gravity of these gases is 0·915.

By elaborate calculations on the principles above indicated, M. Périssé determines the actual temperatures in these gas furnaces as follows:—

	Siemens.	Ponsard.
Initial temperature of the air and the gas.	2012° F.	Air 1742° F. Gas 1562° F.
With the supply of air strictly necessary	3758° F.	3659° F.
With 10 per cent. of air, in excess	3659° F.	3560° F.

Here it is seen that the Siemens furnace has a higher temperature by 99° F. than the Ponsard furnace; and the temperature is at least 540° F. higher than that of other furnaces.

D. K. C.

On the Composition of the Gases of the Bessemer Converter.

By A. Tamm.

(Jern Kontorets Annaler, 1875, p. 120.)

The following experiments were made at Westanfors in Sweden, in September 1874, upon the gases collected at intervals during the blowing of two charges. In the first series, A in the table (see page 315), the charge was 60 cwt., and the blow lasted twenty-seven and a half minutes, while in the second, or B series, the charge was 64 cwt., and the time twenty-two minutes. The gases were collected by a wrought-iron tube, 16 feet long and 1 inch diameter, bent over at right angles at one end for a length of 18 inches. This part of the tube, which was inserted into the mouth of the converter, was coated with fire-clay, and terminated by a per-

Digitized by Google

forated plug of fire-brick such as is used for the ladle stopper. A wooden plug, bored through with a small hole, was inserted in the opposite end of the tube, through which the gas was led by appropriate connections to the glass vessels in which the samples were collected. The gas given off during the boiling period could be ignited, but did not continue to burn; and when it was led through a glass tube, cooled externally, it was no longer inflammable. The converter flame is therefore to be attributed principally to the enormously high initial temperature at which the gases are produced.

The gases first collected carried over carbon, which was deposited in a finely divided state in the collecting tubes. In the later stages of the operation a thin smoke appeared, which deposited a light brown powder when the gas was collected. An analysis of this material collected by subsequent operations gave the following results:—

Silica	17·92
Alumina	2·08
Ferric oxide	15·55
Manganous oxide	61·61
Magnesia	0·25
Lime	0·60
	98·01

besides some carbon, which, together with the oxygen, owing to the small quantity of material available, could not be directly determined. The manganese was assumed to be in the lower state of oxidation, as no free chlorine was evolved by treatment with hydrochloric acid.

The gas analyses were made according to Bunsen's gasometric method. Hydrocarbons were not found in appreciable quantity in any of the samples. The analyses are described in detail, the results being summarised in the following table (p. 315).

The Author, comparing his results with those published by Snelus in 1871, shows that in both cases the carbon is oxidised to the maximum in the first stages of the process, and that as the combustion proceeds carbonic oxide is produced in increasing quantity, with a corresponding diminution in the amount of carbonic acid (or anhydride). The analysis A 4 shows that as total decarburisation is approached the relative proportion of the gases changes in the opposite direction.

The constant presence of free oxygen, which differs from Snelus's results, is discussed with the view of disproving the assumption of the adulteration of the gases with air from the converter mouth or similar sources of error. The cause of the difference is attributed to the small depth of the melted metal in the converter, about 14 inches, which, from its comparatively slight resistance to the passage of the dense blast from the numerous tuyeres, allowed air to pass through unconsumed in a larger proportion than was the case in Snelus's experiments.

Digitized by Google

Series and No.	Time of Blowing.	Composition per cent. in volume.					Per 100 parts by weight of Blast found.		
							In the escaping Gas.		In combination with non-volatile Matters.
—	Minutes.	Oxygen.	Carbonic Acid.	Carbonic Oxide.	Hydrogen	Nitrogen.	Carbon.	Oxygen.	Oxygen.
A 1	3– 5	4·762	9·127	Nil.	Nil.	86·111	3·5	14·1	9·1
2	9–10	1·699	5·998	17·555	0·908	73·840	10·5	19·5	4·2
3	21–23	0·967	4·856	19·322	1·120	73·735	10·8	18·3	5·5
4	26–27	0·555	1·853	14·311	1·699	81·857	6·5	10·2	13·9
B 1	2– 3	7·256	6·608	Nil.	Nil.	86·136	2·5	14·1	9·1
2	8–10	1·296	5·613	15·579	1·112	76·400	9·1	16·8	7·0
3	12–15	0·980	4·144	25·580	1·040	68·256	14·3	22·9	0·9
4	17–19	1·318	2·995	25·606	1·120	68·961	13·6	21·7	2·2

From the composition of the pig metal operated upon, and that of the gases and the steel produced, the Author computes the actual amount of air consumed in the blowing as follows:—

Composition of	Pig Metal.	Bessemer Metal.
Graphitic carbon	2·150	..
Combined „	1·950	0·200
Phosphorus	0·015	0·020
Silicon	1·390	0·033
Manganese	4·665	0·168
Iron (by difference)	89·830	99·579
	100·000	100·000

In the operation A, 60 cwt. of pig produced 51¾ cwt. of Bessemer metal, from which the following table has been constructed:—

	60 cwt. Pig contains Cwt.	51¾ cwt. Bessemer contains Cwt.	Burnt off. Cwt.	Requiring for combustion to	Oxygen. Cwt.
Carbon	2·46	0·10	2·36	Carbonic oxide	3·15
Phosphorus	0·01	0·01	..	..	..
Silicon	0·83	0·02	0·81	Silica	0·93
Manganese	2·80	0·09	2·71	Manganous oxide.	0·79
Iron	53·90	51·53	2·37	Ferrous „	0·68
Totals	60·00	51·75	8·25		5·55

If the whole of the carbon had been burnt to carbonic oxide, an amount of air sufficient to supply 555 lbs. of oxygen would have sufficed for the whole blow, or 9·25 lbs. of oxygen, corresponding to 39·83 lbs. of air, per cwt. of pig metal blown. As, however, the gases include a considerable amount of carbonic acid besides free oxygen, the actual consumption is larger. By averaging the results of the analyses in Series A, the Author concludes that the actual amount of air used is in the proportion of 100 parts by

Digitized by Google

weight for every 8·3 parts of carbon burnt; and as 3·9 lbs. of carbon are found to correspond to 1 cwt. of pig iron, the final calculation shows that an amount of 47·61 lbs. of air at 0 centigrade is actually required for the conversion of 1 cwt. of pig metal into a mild steel by the Bessemer process.

H. B.

On the Effects of Silicon and Manganese on the Properties of Steel.

By M. F. GAUTIER.

(Bulletin de la Société de l'Industrie Minérale, 2nd ser., vol. iv., p. 383.)

This is an account of an interesting series of experiments, by the late Professor Mrazek, of Przibram, on the properties of different alloys of iron, with carbons, silicon, and manganese. The materials used in making the alloys experimented on were iron wire, as pure as possible, and containing about 0·17 per cent. of carbon; silicide of iron; silicide of manganese; metallic manganese; graphite, and pure grey cast iron. Suitable mixtures of these, to produce the alloys required, were fused in Hessian crucibles, under a flux of quartz and cryolite, or quartz and fluor-spar. The crucibles were allowed to cool in the furnace, and the composition of each button of alloy produced was determined by analysis.

The silicide of iron employed was made by fusing together 100 parts of iron wire, 62 of sodium, 242 of quartz, and 105 of fluor-spar. Its composition was as follows:—

Carbon	traces only
Silicon	7·42
Iron	92·58

It was very magnetic, of a hardness between apatite and felspar, and brittle at ordinary temperatures; but at a red heat it was easily forgeable; and at a white heat it also forged well, without cracking at the angles, and it might be welded perfectly. Quenched in water, from a red heat, it hardened slightly, but without alteration in the appearance of the fracture.

Particulars of the analyses and properties of five alloys made by fusing this silicide of iron with different proportions of iron wire, and graphite or cast iron, are given in a table at the end of the Paper. Two of these, containing respectively 0·258 per cent. of carbon with 0·543 of silicon, and 0·176 of carbon with 0·216 of silicon, were soft and tough when cold, forgeable both at a red and at a white heat, and easily welded, though they did not contain any manganese; while any increase in the proportion either of carbon or of silicon rendered the alloy unforgeable to a greater or a less degree. Professor Mrazek concludes from this that the remarkable forgeability and weldability of the silicide of iron itself is dependent on its freedom from carbon.

Silicide of manganese was made by fusing together, in a similar way, a mixture of chloride of manganese, quartz, cryolite, and

Digitized by Google

sodium. The alloy contained 87 per cent. of manganese and 13 of silicon. It was whitish-grey in colour, with metallic lustre, not magnetic, and brittle when both cold and hot. It was unaltered in the air, and resisted the attack of all the mineral acids, except hydrofluoric acid.

Metallic manganese was obtained by fusing, at an intense heat, a mixture of oxide of manganese with oil and lampblack. It was iron-grey in colour, fine-grained, very brittle, and as hard as quartz. In the air, and even in a stoppered bottle, it oxidised rapidly to a brown powder containing scales of graphite. Its composition was

Carbon	combined	0·49
	graphitic	1·00
Silicon		traces
Manganese		98·51
		100·00

On fusing 17 parts of iron wire with 1 part of this metallic manganese, under a layer of cryolite and in a lime crucible, a button of steel was obtained of the following composition:—

Carbon	0·384
Silicon	none
Manganese	1·380
Iron	98·236
	100·000

This was slightly malleable at ordinary temperatures, but cracked at the edges. At a red heat it forged like iron, and was remarkably soft and ductile; at a white heat it also forged well, and welded with the greatest facility. Tempered in water, from a bright red heat, it became brittle, and as hard as quartz. This result is most interesting; as the effect of manganese on steel, in quantity so much greater than that required to prevent red-shortness, does not appear to have been before published.

Particulars are given of twelve specimens of steel made by fusing together silicide of manganese, or metallic manganese, with different proportions of iron wire and cast iron. These all forged at a red heat; but some of them, especially two containing respectively

Carbon	0·28	Silicon	1·02	Manganese	0·004
Carbon	1·51	Silicon	0·16	Manganese	0·240

did not weld. The percentages of sulphur in the specimens, where stated, varied from 0·01 to 0·02. All of them, even one containing as little as 0·15 per cent. of carbon, with 0·38 of silicon and 0·39 of manganese, though soft and tough in their untempered condition, became hard and brittle when quenched in water from a red heat. As, however, Professor Mrazek used, for his carbon determinations, the Eggertz colour test, which is not reliable under 0·2 or 0·25 per cent. of carbon, the amount of carbon in some of these instances may have been estimated too low.

Digitized by Google

Mrazek deduces from his experiments the following conclusions :—

(1). As affecting the forgeability of steel at a red heat, silicon and carbon are detrimental, while the presence of manganese is advantageous.

(2). Carbon affects the forgeability of steel more than silicon. This difference is especially marked in working the metal at a high heat.

(3). The favourable effect of manganese is more sensible in forging at a white heat than at a red heat.

The concluding pages of the Paper are taken up with a theoretical discussion of the conditions that affect the forgeability of steel. Professor Mrazek's hypothesis is that the foreign matters in steel exist as definite compounds, Fe_4C, Fe_4Si or Fe_2Si, Fe_2S, Fe_4P, &c., dissolved in or diffused through an excess of iron; and that the greater the proportion the free iron bears to the sum of these compounds, the greater the forgeability and weldability of the metal.

W. H.

Regenerative Furnaces for Glass-works, etc.

By T. KLEIMVACHTER.

(Moniteur Industriel Belge, 1875, p. 517.)

The chief feature of the design consists in the arrangement of the passages for the waste gases from and of the air to the furnace. They run parallel for a considerable distance. The vertical walls separating them are thin; the special fire-bricks, which are heated by the waste gases from the furnace passing away in one direction, communicate that heat to the air entering adjoining passages in the opposite direction. The highest temperature is reached close to the point where combustion takes place of the coal or other gas with which the furnace is worked. Each furnace is provided with two sets of flues, and air and gas passages; their functions are continuous. The waste gases pass away from both ends of the furnace, while the gas flame enters at the middle portions of the sole; so that the heat is nearly uniform throughout the furnace, and crucibles occupying the corners are as efficiently heated as those at the centre.

The principal advantages claimed are :—

That as the gases and air pass always one way, no reversal apparatus is needed. That as the gas-producer is only in connection with the chimney through the furnace, and as there is no reversal of currents, there are no losses of gas. That the air for the combustion of the gas is progressively heated. That either a reducing or an oxidising flame may be used at will. That a very intense heat is obtainable; and that the furnace is easily managed, economical in first cost, in maintenance, and in consumption of fuel.

W. W. B.

Digitized by Google

Analysis of the White Smoke from a Blast Furnace near Longwy.

By M. L. GRUNER.

(Revue Universelle des Mines, vol. xxxviii., pp. 1–50.)

The ore used at the iron-works of M. d'Adelsward, at Longwy, is mined from ferruginous oolite, with an argillo-calcareous gangue or covering. It is smelted with coke, and a hot blast at a temperature of from 900° to 1,100° Fahr. When the metal is run off, an extremely dense white smoke escapes, and in a short time covers the walls with a thick coat of powder. Five grammes, or about 80 grains, of the deposit were submitted to analysis, when the composition was found to be as follows:—

Soluble in water :—	Sulphate of potash	·3782	
	Carbonate of potash	·0390	
	Chloride of potassium	·0152	
	Soluble silica	·0012	
			0·4336
Insoluble in water :—	Silica	·2298	
	Chalk	·1588	
	Alumina	·0962	
	Protoxide of iron	·0400	
	Protoxide of manganese	·0016	
	Magnesia	·0036	
	Sulphur	..	
			0·5300
Water hygrometric, and in combination			0·0320
			0·9956

Reducing the proportions of the insoluble constituents in terms of unity, and comparing the composition of the slag with that from the blast furnace:

	Insoluble Constituents of the Smoke.	Slag.
Silica	·433	·330
Lime	·300	·437
Alumina	·181	·146
Protoxide of iron	·076	·036
Protoxide of manganese	·003	
Magnesia	·007	·019
Potash	..	·017
Sulphur	..	·007
Sulphuric acid	..	·002
	1·000	0·994

From these analyses, it appears that the slag is basic. It is easily attacked by hydrochloric acid, when intense heat is generated. So also is the insoluble portion of the smoke.

D. K. C.

Digitized by Google

On the Expansion and Specific Heat of Fusible Alloys.

By W. SPRING.

(Annales de Chimie et de Physique, 5th ser., vol. vii., p. 178.)

Being desirous of ascertaining whether the variation in the specific heat of any substance is due to the variation of temperature of that substance alone, or to the variation of the volume of that substance alone, or to the two causes combined, the Author determined on experimenting with certain metallic alloys, which had a point of maximum density at a considerably elevated temperature. The following are the names and the percentage composition and densities of the alloys employed:—

Rose's metal: Bismuth, 48·902; tin, 23·553; and lead, 27·545, corresponding to the formula $Bi^7 Sn^6 Pb^4$.

Darcet's alloy: Bismuth, 49·247; tin, 21·210; lead, 27·553; corresponding to the formula, $Bi^{13} Sn^{10} Pb^8$.

Wood's metal: Bismuth, 55·74; tin, 13·73; lead, 13·73; cadmium, 16·80; whence the formula, $Bi^4 Pb Cd^3 Sn^2$.

Lipowitz's alloy: Bismuth, 49·98; tin, 12·76; lead, 26·88; cadmium, 10·38; which gives $Bi^{11} Pb^6 Sn^5 Cd^4$.

The specific weights of these alloys reduced to vacuo and 4° cent. were found to be for:—

Rose's metal	9·5125
Darcet's alloy	9·6401
Lipowitz's alloy	9·7244
Wood's metal	9·1106

The curve illustrating the variation in volume by heat of Rose's alloy may be divided into five different parts; the first, comprised between 0 and 30° C., shows a regular expansion; the second, between 30° and 45°, gives an exceedingly great expansion; in the third part the metal contracts and attains its maximum density at 52½° C., and then expands regularly; finally the metal becomes liquid and its volume is greatly augmented. The other alloys furnish similar diagrams. The conclusion which the Author draws from his experiments is that as the specific heat of a body may diminish while its temperature increases, if with this increase of temperature there be a decrease of volume, the specific heat is primarily a function of the volume and only secondarily a function of the temperature, if indeed the temperature as temperature has any real influence.

P. H.

On the Absorption of Gases by Iron and Steel.

By MM. TROOST and HAUTEFEUILLE.

(Annales de Chimie et de Physique, 5th ser., vol. vii., p. 155.)

One of the Authors, as colleague of M. H. Saint-Claire Deville, determined the porosity of steel and of platinum at high tempera-

Digitized by Google

tures, and the Authors have since jointly published numerous researches. Graham in his experiments sought to determine what gases were absorbed before fusion of the metal. Caron has ascertained the effects produced by gases disengaged from copper and steel at the instant of solidification. Cailletet has accurately collected and analysed the gases given off from cast iron maintained in fusion in the foundry; and the Authors occupy themselves with the origin and the mode of production of gases arising from the melting of iron and steel. It is generally admitted that iron and steel possess the property of absorbing at high temperatures gases which are partly disengaged when the temperature is lowered, and the Authors seek to show that this disengagement is often accompanied by an appreciable change in the chemical composition. The disengagement of gas corresponding to an enriching in silicium is first treated of, and there is then considered the disengagement of gas simply absorbed by the molten metals; extraction of gases absorbed or imprisoned in solid blocks of iron or steel; experiments on the absorption of carbonic oxide in iron; and on the absorption of hydrogen in finely divided iron—the Authors summing up their results as follows:—

When cast iron is maintained in fusion in contact with silica and silicates, it disengages carbonic oxide, resulting from the action of carbide of iron upon the silica. Under these conditions the iron becomes impoverished in carbon and enriched in silicium. Cast iron in fusion absorbs considerable quantities of hydrogen gas. Silicium much diminishes the absorption of hydrogen. Manganese, on the contrary, greatly augments the absorption. Carbonic oxide is much less absorbable than hydrogen in the different cast irons. The presence of manganese diminishes the absorption of this gas, and may even annul it. Cast irons after their solidification (pig-iron) retain gases, which may be extracted by heating to a temperature not higher than 800° C. (1,472° Fahr.); above this temperature reaction takes place between the elements present. Hydrogen occurs in much more considerable quantity than carbonic oxide in solid cast iron than in liquid iron; it is more energetically retained than carbonic oxide. Manganiferous cast irons retain more hydrogen than ordinary pig. Steel absorbs considerably less gas than cast iron. Hydrogen is here, as in cast iron, in greater proportion than carbonic oxide, and is more energetically retained than the latter. Malleable iron absorbs, on the contrary, more carbonic oxide than hydrogen, and the carbonic oxide is retained with greater energy. The determination of the presence of carbonic oxide in iron or steel wires, or in small fragments of these metals, may be effected in the cold by the action of moistened bichloride of mercury in vacuo. Thus may be learned the limit of temperature that must not be passed, if it be not desired to attribute to absorption the gas due to chemical reaction.

In studying the absorption of hydrogen in iron wire, also in finely divided iron (pyrophoric iron), the Authors have been led to the observation that finely divided pure iron, freed from all

Digitized by Google

condensed gas, decomposes water slowly at ordinary temperature, and rapidly at the temperature of 100° C. (212° Fahr.). The rapidity of the decomposition increases with the finely divided state of the iron.

P. H.

Preservation of Timber. By L. BOULART.

(Annales Industrielles, 6 June, 5 and 19 December, 1875.)

After describing the various processes, now well known, for the preservation of timber by artificial means (which, it is said, originated in France), an account is given of the method pursued by M. Hatzfeld, which differs from all its predecessors. He has ascertained that the woods most resistant to decay are those which are richest in tannic and gallic acids; thus the oak, which furnishes almost all the tan in general use, is of indigenous woods the most durable, whether immersed in water or buried in earth. These properties of oak will be understood when its composition is considered. It contains essentially the elementary cellular tissue of all those vegetables which deposit lignite, forming a hard concretion predominant in resistant woods, as ebony. Oak and similar woods are saturated with a sap containing gummy and azotic substances and colouring matters. The sap of oak contains a notable quantity of tannic acid, which probably acts upon the vegetable tissue of its timber in a manner analogous to that in which tan acts upon animal tissue, with which it forms an insoluble compound. The hardness and colour acquired by oak after being buried for long periods are due to the tannate of peroxide of iron formed by the combination of tannic acid with ochres or salts of iron, existing in more or less considerable quantities in divers earths; and this tannate of peroxide of iron (an essentially insoluble salt) ought to play the same part as the lignite, of which it artificially augments the quantity. M. Hatzfeld therefore proposes for the preservation of various woods impregnation with tannic acid, which gives to the wood the durability of oak. He then proposes to inject a solution of pyrolignite of iron, which in the cells becomes gradually tannate of iron, making the wood similar to oak which has been long buried and has become hard and unalterable. The liquid for injection should be a mixture in water of a tanniferous substance and a salt of protoxide of iron.

The most advantageous tanniferous substance is an extract of the chestnut, costing about 3*d*. per lb.; and the most convenient salt of iron is pyrolignite of iron (20° Beaumé), costing 10·8*d*. per gallon.

According to analyses of these materials, and by analogy with the sulphate of copper processes (described at length), to obtain a solution containing 1 per cent. of pure tannic acid and 1 per cent. of tannate of protoxide of iron, there would be necessary per 22 gallons of liquid, or for four sleepers; 7·7 lbs. of dry extract of

Digitized by Google

chestnut, containing 60 per cent., or 4·62 lbs. of tannin; 3·52 pints of pyrolignite of iron, containing 2,037 grains of iron and 2·2 lbs. of tannin, the cost thus being 6·5*d.* to 7*d.* per sleeper, which is but slightly in excess of the cost by the sulphate of copper process. It is pointed out, however, that tannic acid being widely diffused in the vegetable kingdom, the above preserving liquid, if manufactured on a large scale, could be produced by a direct process at a much lower cost.

Preservation by superficial carbonisation is then considered, particularly with reference to M. Lapparent's gas method. The burners used are those commonly known as 'atmospheric,' but of large size. As soon as the wood is strongly blackened it is sufficiently carbonised, for the film of charcoal need not be more than $\frac{1}{50}$ inch in thickness. The charred part of the wood, which is easily detached, does not resist decomposition, but the browning of the film underneath, while destroying the spores of fungi, hardens the surface and makes it somewhat horny and slightly impregnated with creosote or tarry matter, which prevents their growth. One man can carbonise 10 square feet in five minutes, and should be able to do easily 1,600 square feet per day of ten hours.

M. Hugon, of Paris, has designed apparatus, more particlarly for carbonising the surface of sleepers, at a greatly reduced cost.

W. W. B.

On Lubricating Oils. By MM. FAREZ and BOULLANGER.

(Bulletin de la Société Industrielle de Mulhouse, vol. xix., p. 363.)

The qualities required for an efficient lubricating material are three — unctuosity, neutrality, and unchangeableness; and the Authors admit that there is no single product which combines these three qualities. Mineral oils, when purified, maintain sufficiently well their quality of neutrality and their unchangeableness; but they labour under the disadvantage of being very inflammable, and are deficient in viscosity, particularly at high temperatures; hence they should be mixed with other substances, by which a sufficient degree of unctuosity is produced. The Authors describe the processes employed in the distillation of oil from schist and boghead coal, the only mineral oil manufactured previous to the introduction of petroleum from America. In the distillation of rocks there is always a partial decomposition, and a production of light and inflammable hydrocarburets. The same inconvenience attends the distillation of petroleum; and the Authors observe that the only means of solving the question is to submit the petroleums to successive distillations and rectifications. They have met with products which emitted vapours inflammable under 140° Fahr.

The first improvement in the treatment of petroleum by the Authors consisted in the introduction of superheated steam. By means of a jet of steam of 5 atmospheres, a temperature of from 275° to 290° Fahr. is maintained, and the heavy oils distilled at

Digitized by Google

these temperatures are not inflammable under 250°. Oils are thus manufactured, having a density of 0·86 at 62° Fahr., which do not emit any vapour under 250°. It is added, by way of example, that the heavy petroleum oil used by MM. Dollfus-Mieg and Co. has a density of 0·860, and inflames at 260°.

The "lubricating oil," as used in America, is not acceptable in France. It is inflammable at 212° Fahr., and requires to be relieved of its tarry and volatile elements. The separation is effected by rectification and treatment with acids, alkalies, and water. The temperature of distillation is pushed to from 580° to 660° Fahr., and the oils which remain in the retort are not inflammable below those temperatures. These oils are purified by mixture with sulphuric acid at 150° Fahr., in variable proportions; when settled, the mixture is decanted, treated with caustic alkalies, and washed in water. The product which has been the most thoroughly matured, and is given as the type, is designated oleo-carburet (oléo carbure); it does not emit any vapour, and is uninflammable at 428° Fahr.; it is semi-fluid, resembles green soap in appearance, and is absolutely neutral and unalterable; its chemical composition is represented by equal numbers of equivalents of carbon and hydrogen, the most elevated of the series. It can be easily and intimately mixed with all the fatty substances employed in lubrication to give it the requisite vicosity.

The Authors give the following boiling points and temperatures of inflammability:—

	Density.	Boiling point.	Inflammability.
	Per cent.	Fahr.	Fahr.
Heavy petroleum oil, 1st type . . .	·862	540°	244°
Ditto do. 2nd „ . . .	·860	511°	221°
Boghead oil 1st „ . . .	·864	441°	212°

There is no relation between the density and the inflammability. There follow some examples of the temperatures of inflammability of mixtures of boghead oil with oleo-carburet:—

Boghead Oil.		Oleo-carburet.		Mixture.	
Per cent.	Fahr.	Per cent.	Fahr.	Per cent.	Fahr.
90	176°	10	410°	100	257°
80	176°	20	410°	100	275°
70	176°	30	410°	100	298°

Showing that a mixture containing 10 per cent. of oleo-carburet raised the temperature of inflammability of boghead oil by 81° Fahr.

Mixtures of oleo-carburet with heavy petroleum oil of a density of 0·860 have been tested, and with the following results:—

Petroleum Oil.		Oleo-carburet.	Mixture.	
Per cent.	Fahr.	Per cent.	Per cent.	Fahr.
90	243°	10	100	262°
80	243°	20	100	275°
70	243°	30	100	288°

Whereas a mixture of one-third, or 33 per cent. of colza oil, with two-thirds of petroleum oil, only raised the temperature of inflammability to 257° Fahr.

Digitized by Google

The price of oleo-carburet at Mulhouse is £36 per ton, that of heavy petroleum oil is £18 per ton, and of colza oil, £30 per ton.

D. K. C.

The Aërophore Rouquayral-Denayrouze. By A. HABETS.

(Annuaire de l'Ass. des Ing. sortis de l'École de Liége, 2nd ser., vol. iv., p. 223.)

The aërophore, or compressed-air reservoir, manufactured by M. Denayrouze, for supplying fresh air for respiration and for lamps, has been much employed in collieries and in other situations affected with noxious gases, as well as in submarine operations. The aërophore is of three types. Where it is only required to go a short distance beyond the reach of pure air, it is sufficient to maintain a communication with the air by a long flexible tube, the end of which is fitted with two valves, one for inspiration of air from the tube, the other for expiration. The valves are formed of two sheets of india-rubber, set together like the mouthpiece of a clarionet. With this apparatus a man may advance 100 or 120 feet beyond the pure air—into the flues of boilers, or into hot-air apparatus; or it may be used when smelting furnaces are charged.

Under water, a supply of air under pressure must be maintained, in connection with diving dresses. A depth of about 100 feet, corresponding to from $2\frac{1}{2}$ to 3 atmospheres of pressure, is the prudent limit at which men can work under water, although robust divers may be able to descend to a depth of 130 feet. For ordinary distances from pure air, pressures of from 3 to 4 atmospheres are maintained by two single-acting air-pumps, balanced like those of hand fire-engines. The pistons are fixed, and the cylinders are moved upon them. When not working under water, and when air under pressure is used, the mouthpiece is provided with a regulating chamber and apparatus (very similar to a gas-regulator) by which the air is brought down to a pressure but little above that of the atmosphere, and a similar apparatus gives air to the lamp. But for temporary operations at great distances a portable supply of air, compressed to 20 atmospheres, is taken; to effect which a compound single-acting pump is employed. There are two cylinders, the first of which has six times the capacity of the second. Atmospheric air is drawn into the first cylinder, compressed to 4 atmospheres, and discharged into the second cylinder, where it is compressed and discharged at 24 atmospheres. With this pump, a reservoir of $\frac{3}{4}$ cubic foot is filled with air at 24 atmospheres in from eight to ten minutes. With a quadruple pump, M. Denayrouze has succeeded in compressing air to 40 and even to 60 atmospheres. Six reservoirs of 0·75 cubic foot each, made of steel, are placed and connected together on a small truck; one of them is fitted with the regulator, from which a current of air, slightly compressed, is permitted to escape, and is conveyed to the workman, in the same manner as the current of compressed air under water. Each reservoir carries one half-hour's supply for a

Digitized by Google

man and his lamp, at the rate of more than ½ cubic foot of air at ordinary pressure per minute; and each reservoir, when exhausted, may be replaced by a fresh one.

To simplify the apparatus for air-supply, M. Denayrouze has substituted a single cylinder, having a capacity of a little more than 1 cubic foot, and weighing, with truck, 135 lbs. It supplies air for a man and his lamp, lasting from three-quarters of an hour to one hour. But, recently, in order to dispense with the encumbrance of a long air-pipe, a reservoir, consisting of three steel cylinders, has been arranged like a knapsack to be carried on the workman's back. Its weight does not exceed 26 lbs., and the supply of air lasts for fifteen or twenty minutes.

These portable aërophores retain, for months, the charge of compressed air without serious loss, and may be kept ready for immediate use in emergencies. Many instances of the useful work done with them are described. D. K. C.

On the Artificial Cooling of Air in considerable Quantities, by Contact with a Cooled Liquid. By MM. MIGNON and ROUART.

(Comptes rendus de l'Académie des Sciences, vol. lxxxi., p. 674.)

For experiment the Authors employed a flask with three tubes, having on the bottom a concentrated aqueous solution of chloride of calcium. This is plunged into a freezing mixture; the air enters the apparatus by one tube, and leaves it by another, the third containing a mercurial thermometer. There is an aspirator to produce the motion of the air, and there are flasks, containing a drying material, to measure the effect of cooling on the hygrometric state of the air, and thermometers for measuring the temperatures of admission and release. Three experiments were made, showing that with a certain velocity there was a certain fall of temperature, with half the velocity the same fall, whilst with one-twelfth of the velocity there was three-fourths the fall. In the last case the effects of radiation are considerable, whilst the first two agree, when it is remembered that doubling the velocity of efflux does not halve the duration of contact of air and liquid, which depends only on the velocity of the air in traversing the liquid, through difference of density, and remains sensibly constant.

In practice, instead of the above apparatus, a cylinder was used, having a central axis, with attached circular plates, rotating between discs fitted to the inner side of the cylinder. A stream of the liquid passed over the upper plate, and fell in a cascade from plate to plate. By this means a building of about 4,000 cubic yards was supplied with air so as to maintain its temperature continually at 53° Fahr., although 33,000 lbs. of oil were daily introduced at a temperature of 140° Fahr. To obtain this result, there were passed through the apparatus per hour 57,200 lbs. of air, the temperature of which was lowered 18° Fahr. E. B.

Digitized by Google

Refrigerating Machine.[1] By P. GIFFARD.

(Annales du Génie Civil, vol. xiii., p. 773, pl. 24.)

This machine is said to be capable of producing cold air at temperatures ranging from freezing point down to — 392° Fahr., without the aid of chemical refrigeratives. Expansion of the air may be regulated, so that the temperature of the issuing air may range between 50° Fahr. and — 22° Fahr. The machine consists chiefly of two cylinders placed vertically the one over the other, the lower being for compression, the upper for expansion. Both are provided with double-acting pistons, one rod passing through and working both. The covers of each cylinder are provided with admission and escape valves, and the compression cylinder is fitted at the top and bottom with pipes having rose ends, through which, by a small pump, jets of water are injected to cool the air under compression. From this cylinder the compressed air and its cooling water pass into a reservoir, from which the water is forced on to a cooling apparatus, whilst the compressed and cooled air is passed into the expansion cylinder and thence used. The cylinders are supported upon a bed plate, also carrying a pair of side frames provided with plummer blocks at the tops, forming bearings for the crank shaft from which the pistons receive their reciprocating motion. The crank shaft likewise carries small bevel pinions through which the valves of the expansion cylinder are worked at proper intervals, and gearing by which the pump providing water for the compression cylinder is worked.

The periphery of the pistons is provided with two parallel-sided grooves, the bottom of which is of a V form. Into the inner portion of the parallel part of these grooves are sprung india-rubber rings, of rectangular section, outside which are fitted leather rings of similar section. Small holes are made in either face of these pistons, communicating with the V-form cavity inside the india-rubber, into which the air enters at a variable pressure corresponding to the intensity of compression; the friction on the side of the leather ring being that due to the pressure at any part of the stroke, and the area of the internal diameter of the india-rubber ring; the co-efficient of friction between the leather ring and the cylinder having been ascertained to be equal to 0·10. The escape and admission valves have hard india-rubber faces; an annular groove is formed in one side of these india-rubber rings, into which the air under compression enters and dilates them.

The packing ring in the piston-rod stuffing box is also of india-rubber, with an annular ring in the face towards the piston, the air entering which expands it internally and externally, causing it to fit the stuffing box and the piston rod in the manner of a common hydraulic press leather cup.

---

[1] *Vide* "The Mechanical Production of Cold," by A. C. Kirk. Minutes of Proceedings Inst. C.E., vol. xxxvii., p. 244.

Digitized by Google

As illustrating the value of variable expansion, taking T and t as the temperature of the air before and after expansion, and P and p as the corresponding pressures, and giving $T = +59°$ and $\frac{P}{p} = 2, 4, 6, 8, 10$ ($+59°$ being the temperature of the air entering the expansion cylinder), then

Ratio $\frac{P}{p}$.	Temperature t after expansion. ° Fahr.
2	− 36
4	− 112
6	− 151
8	− 180
10	− 193

Thus, with the air at 10 atmospheres only, it is possible to obtain 193° of cold. W. W. B.

On the General Theory of Duplex Telegraphy.

By L. SCHWENDLER.

(Journal of the Bengal Asiatic Society, vol. xliii., pp. 1 and 218; vol. xliv., p. 47.)

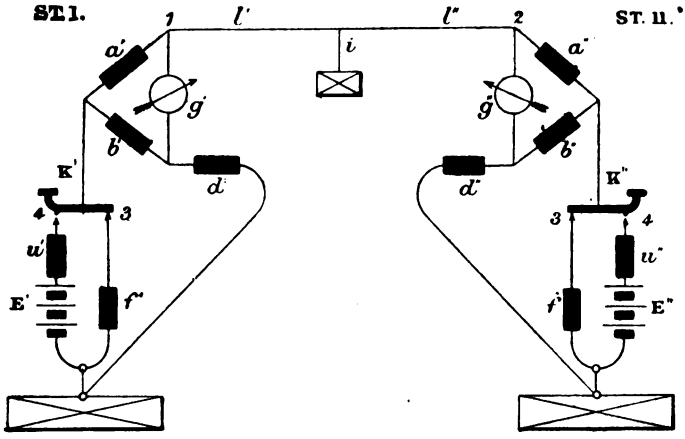
The Author seeks to develop the mathematical theory in its most general form, with the object of determining not only the best arrangement for any particular method, but also the relative values of different methods. After a brief historical sketch from the time of Messrs. Siemens and Halske's English patent in 1849, to the re-introduction of duplex telegraphy by Mr. Stearns, the American telegraph engineer, with an inquiry into the causes which have delayed the introduction of the system, the Author proceeds to a general consideration of the subject.

In ordinary (single) telegraphy the signals are always produced in the same way, *i.e.*, by the signalling current arriving through the line from the distant station; but in duplex telegraphy the signals may be produced by two essentially different ways. If the times of sending of the two stations fall together, *i.e.*, if no current, or a double current, or any difference of currents, is in the line, the signals are produced, so long as this state of line exists, wholly or partly by the battery of the receiving station; they are called 'duplex signals,' and indicate the essential difference between duplex and ordinary telegraphy. If, however, the moments of sending from the two stations do not fall together, the signals are produced as in ordinary telegraphy; and when the two stations are at work 'duplex' and 'single' signals must necessarily follow each other in accidental succession. There are, consequently, two conditions to be fulfilled in duplex working: (1) The receiving instrument of each station must not be affected by its own sending; (2) The duplex and single signals must be of equal strength. If by p is designated the force which acts on the receiving instrument on account of not being able to fulfil the first condition absolutely, by P the force which acts on the same instrument when

Digitized by Google

the distant end is sending alone, and by Q the force which acts on the same instrument when both stations are sending simultaneously, then the first condition (1) is expressed by $p = 0$, and the second (2) by $P - Q = 0$. Further, if p cannot be always kept rigidly equal to zero (on account of unavoidable variations in the system), at least $\frac{p}{P} = D$ should be as small as possible; and this should also be the case with $P - Q = S$. The general problem for duplex telegraphy becomes: D and S are two known functions which must be rigidly equal to zero when no variation in the system occurs; any given variation must be as small as possible, and approximate rapidly towards zero as the variation in the system becomes smaller and smaller. Thus the solution of the problem for any given duplex method will always be a question of the minima and maxima calculus; but the particular cases of duplex working enable the question to be attacked in two different ways; that is, either when considering the line as a variable conductor only, but not acting perceptibly as a Leyden jar; or the line is to be considered as constant in conduction and insulation, but acting as a Leyden jar of large capacity. The Author proceeds to consider the best arrangement of any given duplex method when the line is regarded as a variable conductor, but not as acting perceptibly as a Leyden jar.

I. The Bridge Method: to the comprehension of which the following diagram is necessary:—



E′ electromotive force of the signalling battery; β internal resistance of the signalling battery; K′ the key; g' the receiving instrument; a', b', and d', are branches of the bridge; f' the resistance between the rest contact of the key and earth; u' an additional resistance to be inserted in the battery branch for the better maintenance of balance conditions; i' the resistance of the resultant fault (real absolute insulation of the line) acting at a distance l' from station I., and at a distance l'' from station II. (both l' and l'' expressed in resistances), so that $l' + l'' = l$ the real conductor resistance of the line.

Digitized by Google

L′ it is understood is the conductor resistance of the line measured from station I. and $L' = l' + \frac{i.l''}{i+l''}$; L″ is the conductor resistance of the line measured from station II. and $L'' = l'' + \frac{i\,l'}{i+l'}$; ρ' is the complex resistance of the duplex arrangement in station I., that is, the resistance between point 1 and earth; ρ'' the complex resistance of the duplex arrangement in station II., that is, the resistance between point 2 and earth. In practice, especially with long lines, L′ and L″ will be different from each other. Stating that the great practical advantage of the bridge method is that any kind of instrument which has been used for single working may also be employed for duplex telegraphy, and that this fact must always be of great consideration for any administration that contemplates the general introduction of duplex telegraphy, the Author passes to the consideration of the general expressions for the two functions D and S. This includes the following advantages as practical deductions: that, as balance is re-established by appropriate re-adjustment of one of three available branches, a', b', or d', it is advantageous that the bridge-adjustment be made in b', since this branch acts as the galvanometer branch of a bridge for any current arriving through the line. The rigid fulfilment of the equation $a'\,d' - f'\,g' = 0$ necessitates that $u' + \beta = f$, which, it is suggested, may be maintained by inserting a small galvanoscope in the branch b', and by noting the deflection on the galvanoscope when both stations are sending simultaneously, and again when the station for which β is to be measured is sending alone. Then if these two deflections are equal, $u' + \beta = f$; and if these deflections are not equal u' is altered until they become equal. After the determination the galvanoscope is short-circuited. In practice it is found that a weekly adjustment of u' is sufficient.

The mathematical consideration further leads to important results: viz., that by the following two equations the problem is generally solved:—

$$a = g = d = f = \frac{L}{2},$$

$$b = \frac{a}{3} = \frac{L}{6},$$

by L being understood the measured conductor resistance of the line from that station for which the best resistance arrangement is to be calculated.

The Author thus sums up the results so far obtained: (1) The branches of the bridge, with the exception of the one lying opposite the line, must be equal to each other, and severally equal to half the measured conductor resistance of the line. (2) The branch lying opposite the line should be equal to the sixth part of the measured conductor resistance of the line; and in this, the smallest of all the branches, only readjustment of balance should be made. These conclusions are, however, under the limiting

Digitized by Google

supposition that the line used for duplex working was perfect in insulation, or, more generally, that the real conduction resistance of the line could be neglected against the resistance of the resultant fault. For variations from this case, the results are expressed by the formulæ:—

$$a = d = f = g = w + \beta,$$

$$g = \mathrm{H}\left(\sqrt{1 + \frac{\mathrm{L}}{\mathrm{H}}} - 1\right),$$

where $\mathrm{H} = \frac{l+i}{3}$; but when the insulation is perfect (or, theoretically, $i = \infty$) the results revert to those formerly obtained. These principles have been put fully to the test since June 1874 on the Bombay-Madras line (worked direct 800 miles), on the Calcutta-Bombay (translation) line in two lengths of 850 and 640 miles each, the wire throughout being No. 5½ B. W. G. (diameter = 5¼ millimètres).

II. The Differential Method. The practical inferiority of the differential method, when compared with the bridge method, is that specially constructed receiving instruments on the differential principle are required. Besides, differential instruments must be mechanically more complicated than others, and require, therefore, superior workmanship, entailing greater expense to arrive at working efficiency; and while in the bridge method the balance is obviously independent of the resistance of the receiving instrument, in the differential method the balance is clearly a function of the resistances of the two coils of which the receiving instrument consists; and as these two coils may alter their resistances independently, and not in proportion, as indicated by the balance equation, a new element of disturbance is introduced which the bridge method does not possess. In this system E, β, K, w, f, are as in the bridge system; but the coils of the instrument (wound so as to have opposite magnetic effects) are represented by a (the coil leading to line), and b (the coil leading to earth). The current, split from the middle of the key, passes through a resistance d into coil b, and through a resistance h into coil a, d and h being the adjusting resistances to the coils a and b. This system gives to maxima and minima consideration, the solution that balance in each station must be obtained by a movement of the two acting coils or their armatures, either singly or, better, simultaneously in the same direction, and *not* by an alteration of the resistances in the branches. If this mode of adjusting balance be adopted, then the solution is: $d = h = 0$, *i.e.* these resistances d and h can be eliminated;

$$f = b = w + \beta$$

$$a = \frac{\mathrm{L}}{2} + \frac{b}{4}.$$

One of the sections of the line upon which the bridge system, under the Author's method, is worked, runs from Bombay to

Digitized by Google

Callian, and is exposed to the destructive influence of a tropical sea climate; between Callian and Poona the line passes over the Western Ghâts, and the dense fogs during the cold weather and the heavy rains during the south-west monsoon on these hills seriously affect its insulation. Again, between Bellary and Madras during the north-west monsoon the line is under the influence of an unfavourable climate; the atmosphere, at this time at a high temperature, is saturated with moisture and salt, leaving conducting deposits on the surface of the insulators. During the south-west monsoon the resultant fault is near Bombay; during the hot weather it shifts towards the middle of the line, and in November, when the rain sets in at Madras and the weather on the Bombay side is clearing up, the resultant fault is situated close to Madras. No difficulties have been experienced in working the line; and the Author states that, strange as it may appear from a theoretical point of view, it will, nevertheless, be found in practice that a line worked duplicé carries more than double the traffic of the same line worked singly, for it represents two lines carried on different posts far distant from one another, instead of two parallel lines on the same posts, and consequently the highly injurious effects of voltaic induction are eliminated. Further, the receiving signallers, not being provided with keys, are unable to interfere with messages during their transmission. Corrections and repetitions do not necessitate a stoppage of work, for they are obtained in the following manner: the receiving signaller marks with a cross or underlines the words to be repeated, and places the message by the side of the sending signaller, who calls for the repetitions directly he has finished the message he is transmitting; single working is consequently never resorted to, and the simultaneous exchange of messages and corrections becomes continuous.

P. H.

Measurement of the Velocity of Transmission of Electricity in Suspended Wires. By W. SIEMENS.

(Poggendorff's Annalen der Physik und Chemie, Bd. clvii., p. 309.)

The method employed by the Author differs in some essential points from the plan conceived by him in 1845, for the measurement of the velocity of electricity. The earlier method required two steel rotating cylinders, equal in size and insulated from each other and from earth, as well as two pairs of lines, of which one pair connected the two cylinders, and the other pair two insulated conducting points placed opposite the peripheries of the cylinders. A Leyden jar is inserted between one point and the line connected to it, so that the discharge current must pass through the whole line circuit and leave a spark-mark upon the surface of each of the two cylinders. The difference in distance of the marks produced when the cylinder rotates, from that when the cylinder is at rest,

Digitized by Google

constituted a measure of the time which the electricity required for traversing half the circuit. Considerable difficulties are presented in the preparation of this method. One of these consists in procuring four lines departing from the same place of equal length, and sufficiently well insulated. But the principal difficulty is the mechanical one of making two steel cylinders insulated from one another and the earth, and so light and perfectly centered as to admit of the velocity of 100 to 150 revolutions per second. The following method was therefore designed. It consists in the employment of two Leyden jars or condensers, the inner coatings of which are connected to a point placed close to the rotating cylinder (itself connected to earth), one direct through a short wire, the other through a long wire circuit. The outer insulated coatings are metallically connected. If these are connected to earth the electricity of the inner coatings of both jars will then be freed at the same instant, and be discharged through the point and the rotating cylinder to earth. If the rotation is sufficiently rapid, and the line of sufficient length, two widely separated marks will be produced upon the cylinder, their distance apart being the measure of the time which the electricity requires for passing through the line from the jar to earth. In the experiments this arrangement was modified so that two points, instead of one point, were placed opposite the cylinder and connected, one direct to one jar and the other through the line to the other jar. The points were as near as possible to one another, so that the synchronous marks produced by both on the cylinder while at rest lay close together and practically in one plane parallel to the axis. First a discharge of the jars is taken when the cylinder is at rest, and after that the discharge which serves for the measurement while the cylinder rotates. The cylinder is as light as possible, worked from a solid steel one with a diameter of 1·575 inch (40 millimètres) and 0·394 inch (10 millimètres) length. Its steel axis is furnished with a screw thread in connection with a powerful train of wheelwork by which constant velocity is maintained. The balance-wheel with one hundred teeth carries a small projection which strikes a bell; when the governor is so arranged that the stroke of the bell occurs at the same moment as the tick of a second's pendulum, then the cylinder revolves exactly one hundred times per second. Attached to the apparatus is a microscope for reading off the spark-marks. One millionth of a second can be read off, and one ten-millionth estimated.

Instead of Leyden jars, mica-plate and tin-foil condensers were used. Discharge was effected by cutting through the gutta-percha-covered conducting wire by a smart blow of a knife connected to earth, and thus the troublesome false discharge-marks caused by slow discharge of the condensers were eliminated. The discharge of the jar through a caoutchouc tube filled with water or through a wet string gave, as it appeared, a manifold series of spark-marks surrounding the whole cylinder, but there was no difficulty in establishing the commencement of the discharges. The Author had, on

Digitized by Google

many grounds, deemed it probable, especially as being in accordance with the results obtained by Fizeau and Gounelle, that the velocity of transmission of electricity would be found proportional to the specific conductivity of the material, and he repeated the experiment with a caoutchouc tube filled with sulphate of zinc, 100 feet long, 0·787 inch (20 millimètres) diameter, but was unable to find any difference of time between the direct discharge-mark and that produced by the first partial discharge through the tube. A difference of one five-millionth of a second could easily be observed, so that it is certain that the velocity of transmission of electricity in liquids must exceed 800 German miles per second. Now the conductivity of copper is at least 200,000,000 times that of sulphate of zinc, and therefore, assuming that the velocity of electricity is proportional to the specific conductivity, the velocity in copper will be at least 160,000,000,000 miles per second. That electricity is conducted more quickly in electrolytic conduction than in metals of the same conductivity no one would assume. The contrary is probable, because in electrolytic conduction molecular action comes into play.

By experiments carried out on long telegraph lines the question had to be determined, whether to electricity as to light a determinate measurable velocity can be ascribed, or whether the values of retardation measured by the different observers ought to be wholly or in great measure attributed to the retarding influence due to the inductive capacity of the line. To this end experiments were made in close succession on lines differing as much as possible in length, and in each case the electrostatic capacity of the line was measured. The first set of experiments indicated a velocity of 126,000 miles per second; another set, 143,000 miles per second; a third set gave a mean of 149,916 miles per second; and a fourth, upon which less confidence is placed, 159,092 miles per second. The measurements of the electrostatic capacities of the lines over which the velocity was measured tend to show, that the retardation must be due to some other cause than the influence of inductive capacity. P. H.

On the Electric Conductivity of Inferior Conductors.

By M. Th. du Moncel.

(Comptes rendus de l'Académie des Sciences, vol. lxxxi., p. 864.)

These researches on the conductivity of humid substances have always illustrated the general principle, that the period of the polarisation currents varies relatively to that of the passage of the polarising current; also with the intensity of this current, and the resistance of the circuit. Conductors of a spongy nature give less intensity at the first moment of the polarisation current than liquids, but the current is of longer duration. Inversions

Digitized by Google

are produced, under circumstances which determine upon the electrodes two contrary polarities, not destroying each other, especially when one of these polarities results from a longer or more intense electrification. Planté first discovered this effect in his secondary batteries; and he explained it by saying that the layer of peroxide of lead determined by a long electrification, being not entirely destroyed by inverse electrification of less duration, was only superficially paralysed; but that, when this superficial layer was destroyed, the one beneath it reappeared with all its properties determining a new current of opposite direction to the latter. With liquids which contain no salt in solution, and with inattackable electrodes, it is difficult to explain the phenomenon in the same manner; and on the other hand, it is difficult to admit on the part of the liquid a remanent electrostatic polarity, such as the Author has shown to be produced with electrified stones. Hydrogen absorbed by the platinum may perhaps account for the effect produced; but then it would follow, that plates which do not absorb hydrogen when employed as electrodes could not furnish these inversions of the current. But this is not the case; and it must be admitted, in explanation of these successively inverted currents, that the actions determined by the gases of the water at the moment of their formation, exceed those exercised by the same gases accumulated and in action for some period; or, which is more nearly true, that the remanent polarities on the electrodes determine, after interruption of the battery current, a feeble discharge-current, nevertheless capable of developing secondary electro-chemical action. The Author finds as the result of his experiments, that the currents transmitted by distilled water, and by commercial spirits of wine, are not subject to great variation in intensity when these liquids are in compact mass, but that, on the contrary, they vary greatly when employed to moisten solid bodies into which the liquids can penetrate; then the decrease of the current-intensity with the time becomes as much greater as the humectation is less; doubtless because the liquid particles are quickly transformed into their gaseous elements. With substances unequally humid, there is always produced with copper electrodes a current traversing the exterior circuit, from the driest to the most moist part. In the case of two platinum electrodes, the one in moist sand, the other in drier sand, there is always a definite current flowing from the electrode in the moister sand to that in the drier sand. The effects of heat upon platinum electrodes in sand uniformly moist are very complex, since the thermo-currents are often in contrary direction to the polarisation currents. The results have an indirect bearing on the polarisation of earth-plates.

P. H.

Digitized by Google

Fluid Dielectric Constants. By P. SILOW.

(Poggendorff's Annalen der Physik und Chemie, vol. cliii., p. 389.)

The theory of dielectrics originating with Faraday has more recently been extended by Maxwell and Helmholtz. The greater part of this theory has been proved experimentally by Boltzmann, Schiller, and others, but an important law has hitherto been left unstudied. Helmholtz states that, when the electric masses E and E' lie in a dielectric medium of which the dielectric constant is D, their mutual influence is as $\frac{E}{\sqrt{D}}$ and $\frac{E'}{\sqrt{D}}$ in air (D for air being taken = 1); that is, the attractive force F of the two masses E and E' is

$$F = A\frac{1}{D}\frac{E\,E'}{r^2},$$

where r is the distance between the masses. Another important law in the theory of dielectricity is that, when a conductor of the capacity γ is in contact with a point of constant potential V, the quantity of electricity, e, which it can assume is $e = \gamma DV$, where D is the dielectric constant of the surrounding medium.

The dielectric medium experimented upon was oil of turpentine; and for this, by a simple modification of Thomson's electrometer, the Author was enabled to find the dielectric constant

$$D = 2{\cdot}221$$
$$\sqrt{D} = 1{\cdot}490,$$

and to prove the experimental truth of the foregoing principles. As, according to Maxwell's electromagnetic theory of light, the square root of the dielectric constant of an insulating medium should be equal to the index of refraction for infinitely long waves, it must follow from Cauchy's formula for the relation between the refraction index (v), and the wave-length (λ), viz.,

$$i = A + \frac{B}{\lambda^2},$$

that

$$\sqrt{D} = A.$$

A for the mean of the Fraunhofer's lines D, b, F, G, is 1·459. The difference between A = 1·459 and $\sqrt{D}$ = 1·490 appears great, but it is not wider than that given by the methods of Boltzmann and Schiller. P. H.

Digitized by Google

Automatic Hughes' Apparatus.

(Annales Télégraphiques, 3rd ser., vol. iii., p. 480.)

Automatic telegraphic transmission possesses certain incontestable advantages. Besides the regularity and accuracy of the signals, the work-capacity of a wire is sensibly increased. As far back as 1861, an automatic arrangement was proposed for the Hughes' apparatus by M. Renoir; but the system of M. Girarbon possesses the advantage that it is easily adapted to the existing Hughes' apparatus, and can be as easily and momentarily replaced by the ordinary key transmission. The basis of the system is the automatic chain. This chain is in the form of a narrow ladder, of which the sides are two interlaced cords, coupled parallel by the rungs, which are flattened metallic rings. In each space between two rings, between the double lacets, slides a metallic traverse, which is prevented from quitting the chain by a central stop. All these traverses are of equal length, and each carries a letter, figure, or conventional signal. The composition of the despatches is effected by a dial-plate composer in which, by the depression of the lever on the dial corresponding to the required letter, the proper traverses in the chain are thrust forward. The chain thus composed or arranged is carried to the transmitting cylinder, where it controls the contacts of the transmitting lever in such a manner as to give the required number of contacts to actuate the type wheel, similarly as if the signal were sent by the key.

P. H.

Lightning-Conductors. By E. Saint-Edme.

(Comptes rendus de l'Académie des Sciences, vol. lxxxi., p. 949.)

The Author suggests that instead of platinised points for lightning-conductors, which have low conductivity, nickelised or nickel-plated iron should be employed. The nickel surface has a conductivity a little above that of the mass of iron, and it is not in the least subject to oxidation. It is even proposed to nickelise the rod throughout, which would result in the following of the principle laid down by Franklin, that lightning-rods should be of only one metal.

P. H.

Digitized by Google

Experiments with the Gramme Electro-magnetic Machine.

By M. TRESCA.

(Comptes rendus de l'Académie des Sciences, vol. lxxxii., p. 299.)

The Author had for some time desired to determine directly the amount of work expended in the production of the intense light given by electro-magnetic machines. An old experiment made on one of the machines furnished by the Alliance Company at the Invalides gave an approximation, but it became interesting to ascertain the results furnished by the new machines of M. Gramme. The experiments took place at the workshops of MM. Sautter and Lemonnier, where a dynamometer had been set up. The high velocity at which the machines must be driven rendered the use of the dynamometer difficult, but the results were ultimately satisfactory. The work done was measured with all the exactitude desirable; but this was not equally the case with the luminous intensity. Experiments were made with two sizes of apparatus, one of which was 1,850 times the luminous power of the standard lamp, while the other was 302 times the standard. The photometer employed was of the direct-light kind, and the disc was maintained at a constant distance of 43 yards from the 1,850-light, and at 22 yards from the 302-light, while the standard lamp, a Carcel consuming 40 grammes per hour, was the one that was moved until the correct image on the photometer was obtained. The variations in the light, owing to irregularity in the composition of the carbon points, presented much difficulty in the photometric measurements. The light of the large machine was derived from a lamp constructed in the workshops of M. Gramme, with carbons of 81 square millimètres (0·125 square inch) section; the second was connected to one of M. Serrin's lamps, with carbons of the same size.

The following are the results obtained:—

LARGE MACHINE (16th October, 1875).

Ratio of photometric distances . . . . . 40 : 0·93
Ratio of intensities . . . . . $(40)^2 : (0·93)^2 = 1,850$.

Dynamometer Revolutions per Minute.	Mean Ordinates of Diagram. mm.	Work in Kilogrammètres per Second.
238	22·50	678·28
251	18·89	600·56
248	21·74	682·82
244	16·60	513·00
241	15·59	475·86
244	16·65	516·23
Mean, 244		576·12 or 7·68 HP.

Work per 100 burners . . . . . 7·68 : 18·50 = 0·415 HP.
„ burner per second . . . 0·31 kilogrammètre.

Digitized by Google

To ascertain the velocity of the axle of the large machine, the dynamometer revolutions should be multiplied by 5·22; so that 244 × 5·22 = 1,274 turns per minute. For the small machine the dynamometer revolutions must be multiplied by 3·65.

SMALL MACHINE (4th December, 1875).

Ratio of photometric distances . . . 20 : 1·15
Ratio of intensities . . . . . $(20)^2 : (1·15)^2 = 302·4$.

Dynamometer Revolutions per Minute.	Mean Ordinates of Diagram. mm.	Work in Kilogrammètres per Second.
234	7·11	201·73
238	6·66	200·79
244	7·42	229·42
Mean, 239		210·65 or 2·81 HP.

Work per 100 burners . . . . . 2·81 : 3·024 = 0·92 HP.
,, burner per second . . . 0·69 kilogrammètre.
Velocity of axle of machine = 239 × 3·65 = 872 turns per minute.

The expense attending the use of the machine may be estimated from these results, and from the fact that the Sautter workshops, of 1,435 square yards area, are lighted by three lamps of 100 standard lamp-power each, consuming each 10 to 12 millimètres (0·39 to 0·47 inch) of carbon per hour, at a cost of 1·9*d.* per hour. The Author comes to the conclusion that the cost of the electric light of 1,850-power is, as far as regards the mere cost of coal consumed to work the engines, only one-fifteenth part of that of gas at Paris prices, or one-hundredth part of the cost of oil.

P. H.

On the Electric Light for Industrial Purposes.

By H. FONTAINE.

(Revue Industrielle, vol. vii., p. 1.)

The practical solution of this question has been made with the Gramme machine, applied to a Serrin lamp. As light-unit, the Carcel burner or lamp was adopted, which, consuming 23·68 drams of refined oil per hour, with a flame of 1·38 inch, gives a light equal to that of seven stearine candles, each burning 5·64 drams per hour. It was found that the motor-force required to drive the machine did not in any case exceed 1 kilogrammètre per second for each light-unit produced. The carbon points cost at the present time 4¾*d.* per foot, whatever the section, but this expense would probably diminish under other circumstances of production. Four magneto-machines of 100 Carcel standard light-power each, worked by a portion of the force of a powerful motor, would not consume more than 4·4 lbs. per HP. per hour of fuel. This for 400 kilogrammètres per second, or 5½ HP., corresponds to 24·2 lbs. of coal. Thus an electric light equivalent to 400 Carcel burners would

Digitized by Google

consume per hour 12·6 inches of carbon at 4¾*d.* per foot, and 24·2 lbs. of coal at about 0·13*d.* per lb., or a total of 8·13*d.* For the same light with gas the cost would be that of 1,483 cubic feet, at 6*s.* 8*d.* a thousand, or 10*s.*, being in the ratio of 1 : 14 as the relative cost of electric light and of gaslight. Allowing about 1,000 hours use per annum, interest upon capital invested in the machines would raise the cost of the light by another franc per hour; and if motor-force were not in existence this would be still further increased by increased special consumption of fuel, and interest upon capital to from 25·6*d.* to 30·4*d.* the hour, decreasing the ratio to 1 : 4. Using illuminating gas, as a motor in an Otto and Langen gas-engine, the ratio would fall to 1 : 3, which is the most unfavourable case considered. The Author gives the expense and detail of cost actually incurred by several works using the electric light, varying from 2*s.* 4½*d.* per hour for a 400-power light (which need not, it appears, radiate from only one lamp, but may be dispersed from several lamps at different parts of the works), including all expenses and interest, to 6·8*d.* per hour for a 300-power light in one case, where the motive power is partly derived from a turbine. P. H.

On the Accuracy of Chain Measurements. By JOSEPH WASTLER.

(Zeitschrift des Oest. Ingenieur- und Architekten-Vereins, vol. xviii. p. 33.)

This is an investigation into the accuracy of two hypotheses advanced in the "Journal for Surveying," viz., whether the mean error in chain measurements is proportional to the square root of the length, conformably to the method of least squares (Hypothesis I.), or whether it is directly proportional to the length (Hypothesis II.).

Professor Jordan's unsuccessful test of these hypotheses, from all the data then obtainable, only deduced a probability of either one or the other being in turns correct, and this in spite of his conviction that Hypothesis II. is "theoretically untenable." The Author gives his own investigation, based on what he calls "double (chain) measurements" made during his survey of the town and suburbs of Gräz in 1869 to 1872. In order to prove if the error progressed constantly with the length, the measurements were arranged in seven groups from 0–20, 20–40, 40–60, 60–80, 80–100, 100–120, 120–140 fathoms (Klafter), giving a total of 845 "double measurements," and the results have been tabulated, with details as to the number (n) in each group, and also the number of times differences (d) occurred between two measurements of the same line in each group.

Assuming M to denote the mean error of the mean length in any group, he deduces by the method of least squares

$$M^2 = \frac{[d\,d]}{2n} \text{ or } M = \sqrt{\frac{[d\,d]}{2n}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Digitized by Google

In this way values for M_I, M_{II} . . . . M_{VII} are obtained as under:

Mean Length, $\frac{[l]}{n}$	Mean Error.
15·32 fathoms	M_I 0·0051 fathoms
30·08 ,,	M_{II} 0·0103 ,,
48·14 ,,	M_{III} 0·0144 ,,
69·70 ,,	M_{IV} 0·0166 ,,
87·94 ,,	M_V 0·0224 ,,
109·66 ,,	M_{VI} 0·0241 ,,
129·33 ,,	M_{VII} 0·0261 ,,

from which the fallacy of Hypothesis II. is proved, since by it the error should increase proportionally to the length, and therefore M_{VII} should be more than 4 M_{II}, which is not the case.

Proceeding with Hypothesis I., if μ = the mean error of the unit length obtained from the differences d of the double measurements, then by the method of least squares,

$$\frac{d'}{\sqrt{2}} = \mu\sqrt{l'}, \quad \frac{d''}{\sqrt{2}} = \mu\sqrt{l''}, \quad . \quad . \quad . \quad . \quad \frac{d^n}{\sqrt{2}} = \mu\sqrt{l^{(n)}},$$

from which is obtained the equation

$$[d\,d] = 2\,\mu^2\,(l), \text{ or } \mu^2 = \frac{[d\,d]}{2\,[l]} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Professor Dienger in 1858 found the subjoined value for μ^2, and this was afterwards arrived at by Professor Jordan in another way, viz.:

$$\mu^2 = \frac{1}{2\,n}\left[\frac{d\,d}{l}\right] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

This equation, though really more accurately derived than equation 2, is not preferred to it by the Author, inasmuch as the latter is far simpler in practice; for while in equation 3 each single 845 d^2 is divided by the l belonging to it, as well as by four to five figures of ciphers, and then added, by equation 2 the d^2 is added at once and divided by the sum of l: in the one case seven divisions only are necessary, in the other 845.

Substituting in equation 2 for $\frac{[d\,d]}{2}$, the value found in equation 1, another proof is obtained for the accuracy of equation 2, viz.:

$$\mu^2 = \frac{n\,M^2}{[l]} \text{ or } M = \mu\sqrt{\frac{(l)}{n}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Digitized by Google

The values of μ in each group are next computed by equation 2, viz.:

From	Group	I., $\mu = 0{\cdot}00132$
,,	,,	II., $\mu = 0{\cdot}00188$
,,	,,	III., $\mu = 0{\cdot}00208$
,,	,,	IV., $\mu = 0{\cdot}00199$
,,	,,	V., $\mu = 0{\cdot}00239$
,,	,,	VI., $\mu = 0{\cdot}00230$
,,	,,	VII., $\mu = 0{\cdot}00229$

Here the chief feature is the great difference of the error in Group I. from that in the others; but this is quite justifiable, as half the lines in it, viz. those under 10 fathoms, do not share in the greatest errors due to chaining, which arise from connecting the chain lengths to each other: besides, the reading for such short lines is far too rough, giving invariably an agreement to two places of decimals (or no error), so that the measurements of Group I. must appear more accurate than they really are. The values for μ in the other six groups agree fairly enough, and from them the arithmetical mean is obtained—

$$\mu = 0{\cdot}00216 \pm 0{\cdot}00026 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where the term with $\pm$ affixed to it denotes the probable inaccuracy of μ.

Equation 4 affords the means of testing this last deduction, for by computing M by it, and comparing it with the M obtained from the observations, very small differences result, amounting at the most (viz. in Group II.) to only 12 per cent. These differences should therefore only be set down as observation errors, so that by this investigation Hypothesis I. is perfectly verified.

Turning once more to Hypothesis II., and applying it in the same way, the Author shows that it sufficed tolerably well for short lines, but that for longer ones, and those therefore where on account of the great number of chain lengths the law of observation errors would be more decidedly apparent, it was useless. He also points out that in this case it was unnecessary to exclude Group I. in establishing a mean value for μ.

He concludes by showing how, under Hypothesis I., to convert fathom into mètre measurements, and gives tables of both Jordan's and his own values for the mean error in a chain measurement, computed by this Hypothesis, accounting for his own results being more favourable from the fact that Jordan founded his table on data taken from measurements in fields, while his own chaining was carried out almost exclusively on the stone pavements or macadamised streets of the town of Gräz.

E. H. C.

Digitized by Google

INDEX

TO THE

MINUTES OF PROCEEDINGS,

1875–76.—PART II.

ABEL, F. A., elected associate, 1.—Remarks as to estimating the illuminating power of coal gas, 165.—Ditto as to the use of Prof. Crookes' radiometer as a standard, 165.

Abernethy, J., remarks as to Holyhead new harbour, 122.—Ditto as to the tendency of the rubble mound to become converted eventually into a shingle beach, 122.—Ditto as to his preference for a vertical wall for works of that nature, 123.—Ditto as to Aberdeen harbour, 123.

Adams, H. W., steam brick-kiln, 285.

———, Prof. W. G., remarks as to estimating the illuminating power of coal gas 169.—Ditto as to Prof. Crookes' radiometer as a means of testing gas, 169.—Ditto as to the applicability to gas testing of Mr. Willoughby Smith's discovery, that the electrical resistance of selenium is diminished by exposure to light, 169.—Ditto as to a comparison of the intensities of different sources of light, 170.

Address of Mr. Stephenson, President, on taking the chair for the first time after his election, 1.—Separation of goods and mineral trains from passenger traffic on railways, 2.—Harbours of refuge, 4.—Ocean steam navigation, 7.—Loss of steam vessels at sea, 8.—Capital and labour, 10.—Conclusion, 17.

Adie, P., remarks as to the probable errors of levelling, 200.—Ditto as to refraction as a cause of error, 200.

Aërophore Rouquayral-Denayrouze, 325.

Air, on the artificial cooling of, by contact with a cooled liquid, 326.

——, on the co-efficient for expansion of air under atmospheric pressure, 300.

Airy, Sir G. B., remarks as to the probable errors of levelling, 193.—Nature of the mathematics concerned in a geodetic survey, 193.

——, W., "On the Probable Errors of Levelling," 174.—Ditto as to the 'dumpy' and 'Italian Y' levels, 201.—Ditto as to a high degree of accuracy being necessary in levelling for geodetical purposes, 201.—Ditto as to the levelling of Mr. Bunt and Dr. Whewell, 202.—Ditto as to errors in reading the bubble, 202.—Ditto as to unequal illumination of the staves, 202.—Ditto as to the superiority of the Indian and the Swiss levelling to the English, 203.—Ditto as to there being no influence exercised by the elliptical shape of the earth, 203.—Ditto as to the sinking of the staff in soft ground, 203.

Allison, J., elected associate, 95.

Alloys, on the expansion and specific heat of fusible, 320.

Andé, rebuilding the bridge at, 242.

Digitized by Google

André, G. G., remarks as to the ventilation and working of railway tunnels, 63. —Ditto as to the vitiation of the air by carbonic acid having been overestimated, 63.—Ditto as to carbonic oxide in the upcast shaft of a furnace-ventilated mine, 63.—Ditto as to the upward action of heated gases depending upon the air in a tunnel being quiescent, 64.—Ditto as to ventilating the carriages themselves while in a tunnel, 64.
Antoine, C., on the mechanical properties of saturated vapours in vacuo, 283.
Axles, on the insufficiency of the tests in use for steel, 307.

Bachhoffner, G. H., report on the ventilation of the Metropolitan railway, referred to, 25.
Ballyteige Lough. *Vide* "Lagoons on the South-east Coast of Ireland."
Bannow Bay. *Vide* "Lagoons on the South-east Coast of Ireland."
Barlow, W. H., remarks as to the ventilation and working of railway tunnels, 65. —Ditto as to the distinction between the two processes of natural and artificial ventilation, 65.—Ditto as to a proposed division formed of iron with openings above the engine chimneys, 65.—Ditto as to Prof. Crookes' radiometer as a standard for testing the illuminating power of coal gas, 165.—Ditto as to the probable errors of levelling, 195, 199.—Ditto as to the levels taken from Portishead to Axmouth for the British Association, 195.
Barton, J., "Carlingford Lough and Greenore," 131.—Remarks as to ditto, 147.—Ditto as to Cranfield Point, 147.—Ditto as to blocks in front of the quay wall being more expensive than bags of concrete at the back, 147.—Ditto as to the velocity of the current, 147.—Ditto as to the fenders, 147.—Ditto as to the suggested tidal docks being inexpedient, 148.—Ditto as to the mode of lowering the bags of concrete, 148.
Belgrand, H., floods of the Garonne and other rivers in France in 1875, 261.
————, on the flood of the Seine in February-March 1876, 262.
Bell, V. G., remarks as to the ventilation and working of railway tunnels, 50.—Ditto as to the probable mode of working of traffic in the Channel tunnel, 51. —Ditto as to comparing the ventilation of long tunnels with that of mines, 52.—Ditto as to a proposed system of ventilating by longitudinal airways, 52.—Ditto as to the difficulties having been hitherto greatly underestimated, 85.—Ditto as to the pipe arrangement in the Mont Cenis tunnel, 85.—Ditto as to the allegation that the standard of purity of 8½ parts of carbonic acid in 10,000 parts of air was too high, 85.—Ditto as to liquid fuel for tunnel locomotives, 86.—Ditto as to a suggested horizontal brattice, 86. —Ditto as to proposed hot-brick locomotive, 86.—Ditto as to the relative advantages of one double-line tunnel or two single-line tunnels, 87.
Bennett, H. W., admitted student, 1.
Binnie, A. R., remarks as to the probable errors of levelling, 196.
Boileau, P., on the flow of water in pipes, 257.
Bonhomme, P., the foundations of the Saulze bridge, 244.
Bonnin, R., account of the rebuilding of the bridge of Andé over the Seine, 242.
Boulart, L., preservation of timber, 322.
Boule, M., new type of movable dam, 268.
Boullanger and Farez, MM., on lubricating oils, 323.
Bradbury, A. B., memoir of, 224.
Break, the Heberlein, 254.
Breakwater, Aberdeen, use of concrete in bags at, referred to, 149.
— ————, Holyhead. *Vide* Harbour.

Digitized by Google

Brentnall, W., elected associate, 95.
Brick-kiln, steam, 285.
Bridge at Andé on the Seine, rebuilding of the, 242.
———, Saulze, foundations of the, 244.
Brooks, W. A., remarks as to Carlingford Lough and Greenore, 143.
Brounger, R. E., elected associate, 1.
Bunning, T. W., remarks as to the ventilation and working of railway tunnels, 76.—Ditto as to a proposed attachment behind the funnel of a locomotive of a frame fitting one-half the tunnel, and fringed with brushwork, 76.
Bunt, —, his levelling from Portishead to Axmouth referred to, 193 *et seq.*
Burt, H. P., admitted student, 1.

Cadett, W. J., elected associate, 95.
Calver, Capt., R.N., remarks as to the Holyhead new harbour, 117.—Ditto as to the defective nature of the design, 118.—Ditto as to an accumulation of silt observed in the harbour in 1857, 119.—Ditto as to Carlingford Lough and Greenore, 147.
Canal, Ganges, hydraulic experiments on the, at Roorkee, 263.
Canning, Sir S., elected member, 95.
Car, Mékarski's compressed-air tramway, 254.
"Carlingford Lough and Greenore," 131.—General description of the lough and its entrance, 131.—Projects for the improvement of the navigation, 132.—Application of the Newry Navigation Company for powers from the Board of Trade, 132.—Application to the Public Works Loan Commissioners, 133.—Operations for dredging the bar, 133.—Nature of the material dredged, 134.—Cost of dredging, 135.—Deep-water marine station projected in 1862, 135.—Works at Greenore, 136.—Landing stages, 137.—Quay wall, 138.—Method of lowering the concrete blocks, 140.—Open steamer dock, 140.—Cost of the works, 141.
Carter, W. A., elected associate, 95.
Cartmell, J., elected associate, 95.
Cay, W. D., remarks as to Holyhead new harbour, 126.—Ditto as to the rubble mound probably requiring considerable repairs at some future time, 126.—Ditto as to the possibility of constructing a cheaper work of concrete, 127.—Ditto as to Carlingford Lough and Greenore, 148.—Ditto as to the history of the modern employment of liquid concrete in bags, 149.—Ditto as to the depositing of 9,000 cubic yards of concrete at Aberdeen on this system during the summer of 1875, 149.
Cements, experiments on, at Bangalore, 238.—Adhesion of mortars to brick and stone, 238.—Best way of using mortars of sand and fat lime, 238.—Best proportions for mortars of fat lime and Soorkee (pounded brick) for masonry, 239.—Proportion of actual strength to tensile strength obtained with standard briquettes of mortar, 240.
Chabassu, M., viaduct over the valley of the Luech, 246.
Chain measurements, on the accuracy of, 340.
Channel tunnel, referred to, 18 *et seq.*
Chatterton, G., admitted student, 1.
Chesil Bank, theory of the formation of the, 217.
Chiavacci, V. *Vide* Ciocca.
Chubb, H. W., admitted student, 1.

Digitized by Google

Ciocca, F., and Chiavacci, V., the improvement and enlargement of the port of Genoa, 271.
Clark, D. K., remarks as to the ventilation and working of railway tunnels, 87.—Ditto as to there being only two systems of ventilation for tunnels traversed by steam locomotives—the "separate" system and the "dilution" system, 87.—Ditto as to the amount of gaseous products per mile arising from English coal, 87.—Ditto as to the general proportions of air, gaseous products, and steam contained in a tunnel after being traversed by one train, 88.—Ditto as to the velocity of ventilation through the entire sectional area of the tunnel, 90.—Ditto as to the gross or indicator power required, 91.—Ditto as to a suggested longitudinal brattice, 92.
Clarke, S., memoir of, 225.
Coal, deep sinking for, at Peremba in Upper Silesia, 287.
Conductors, electric conductivity of inferior, 334.
———, lightning, 337.
Coode, Sir J., remarks as to the design for the Holyhead new harbour, 127.—Ditto as to the wagons used for tipping the stone, 127.
Cook, B. W., admitted student, 1.
Cooke, G. C., memoir of, 228.
Cooling of air, on the artificial, by contact with a cooled liquid, 326.
Cooper, R. E., transferred member, 1.
Courtney, Major E. H., R.E., remarks as to the probable errors of levelling, 201.—Ditto as to the proposals of Mr. Airy involving too much office work, 201.—Ditto as to the causes of the superiority of the Swiss levelling, 201.
Cowper, E. A., remarks as to the ventilation and working of railway tunnels, 83.—Ditto as to the friction of the air being excessive in long tunnels, 83.—Ditto as to the full section of a long tunnel being better adapted for obtaining a quick current than any arrangement of diaphragms, 83.—Ditto as to the probability of being able to conduct the traffic other than by locomotive power, 83.—Ditto as to a single tunnel divided by a vertical wall in the middle, 84.
Crookes, Prof., his radiometer referred to, as a probable standard for estimating the illuminating power of coal gas, 164 *et seq.*
Croullebois, M., on the value of the co-efficient of expansion of superheated steam, 284.
Cubitt, Sir W., method followed by, in blasting the Round Down Cliff at Dover, referred to, 113.
Cunningham, Capt. A., hydraulic experiments at Roorkee, 263.
———, D., elected member, 95.

Dam, concrete, for the Geelong waterworks, 241.
——, new type of movable, 268.
Dantzic irrigation works, on the chemical composition of the sewage liquid and effluent water of the, 276.
———, the results of sewage irrigation at, 279.
Darbishire, G., admitted student, 1.
De Coppet, —, theory of superfusion and supersaturation, after the principles of the mechanical theory of heat, 298.
Dielectric constants, fluid, 336.
Diving-bells. *Vide* The aërophore Rouquayral-Denayrouze, 325.
Dixon, J., remarks as to the ventilation and working of railway tunnels, 55.

Digitized by Google

Dobson, G. C., his tipping wagons at Holyhead breakwater works, referred to, 105.

Douglass, J. N., remarks as to the Holyhead new harbour, 119.—Ditto as to the advantages of adhering to the rubble mound with the materials close at hand as at Holyhead, 120.—Ditto as to the hollow form of the breakwater being a source of weakness, 120.—Ditto as to the illuminating apparatus in the light-house at the end of the breakwater, 120.—Ditto as to estimating the illuminating power of coal gas, 168.—Ditto as to his improved "London Argand" burner used at the Caistor leading lights, Great Yarmouth, 168.—Ditto as to the specified candle power of coal gas being raised as the burners were improved, 169.

Dunn, E. A., elected associate, 1.

Dynamics,—on the relative value of blows and pressure, 302.

Electric conductivity of inferior conductors, 334.

——— light for industrial purposes, 339.

Electricity, measurement of the velocity of transmission of, in suspended wires, 332.

———. *Vide* Fluid dielectric constants, 336.

Electro-magnetic machine, experiments with the Gramme, 338.

Elwes, R. G., remarks as to the probable errors of levelling, 197.—Ditto as to the maximum error allowed in the Irrigation Department in India, 197.

Embankment, on the slipping of the Tiligul, on the Odessa-Balta railway, 250.

Escher, Wyss, and Co., steam railway pontoon constructed by, 286.

Farez and Boullanger, MM., on lubricating oils, 323.

Fisher, B. J., elected associate, 95.

Ffolkes, M. W. B., elected associate, 1.

Flood of the Seine in February–March 1876, 262.

Floods of the Garonne and other rivers in France in 1875, 261.

Flow of water in pipes, on the, 257.

Fontaine, H., on the electric light for industrial purposes, 339.

Foundations of the Saulze bridge, 244.

Fox, C. D., remarks as to the ventilation and working of railway tunnels, 76.—Ditto as to the condition of the Metropolitan District railway, 77.—Ditto as to the practice in opening up mines, 77.—Ditto as to the retrograde character of proposed expedients for working long tunnels, 77.—Ditto as to the pneumatic system, 78.—Ditto as to the wire-rope system, 78.

Fuel, on the use of pulverised, 289.

Furnace, blast, analysis of the white smoke from a, 319.

Furnaces, gas, on the temperature of, 312.

———, regenerative, for glass-works, 318.

———, utilisation of heat in, 310.

Gas, "On Estimating the Illuminating Power of Coal Gas," 151.—Want of a generally recognised standard burner for the purposes of gas photometry, 151.—Experiments of Mr. Kirkham and Mr. Sugg, 151.—Jet-photometer of Mr. G. Lowe, 151.—Parliamentary standard of comparison, 152.—Standard burner designed by Dr. Letheby and Mr. Sugg in 1863, for 14-candle gas, 153.—Standard burner for 16-candle gas, 154.—Standard 'London' burner for 18-candle gas,

Digitized by Google

155.—Mr. Haywood and Dr. Letheby's definition of the illuminating power of gas, 156.—Principle recommended by the committee on the Metropolitan Gas Bill, 1868, 156.—Constant-flame burner for 12 to 30-candle gas proposed by Mr. Sugg, 156.—Mode of experimenting with the constant-flame burner, 158.—
Gas furnaces, on the temperature of, 312.
Gases, on the absorption of, by iron and steel, 320.
——, on the composition of, of the Bessemer converter, 313.
——, on the laws of, 299.
——, on the specific heat of, 301.
Gautier, F., on the effects of silicon and manganese on the properties of steel, 316.
Geelong waterworks, concrete dam for the, 241.
Genoa, improvement and enlargement of the port of, 271.
Giffard, P., refrigerating machine, 327.
Giles, A., remarks as to Holyhead new harbour, 116.—Ditto as to the acknowledged necessity for harbours of refuge, 116.—Ditto as to the alterations from the original design, 117.—Ditto as to an upright wall affording a better breakwater and requiring less repairs than a long sea slope, 117.—Ditto as to a proposed form of breakwater, consisting of an iron skin filled with concrete or other material, 117.—Ditto as to Government alone being able to undertake such costly works as the Holyhead harbour, 117 and 125.—Ditto as to the probable errors of levelling, 198.—Ditto as to the extreme precision required in geodetical surveys being unnecessary in engineering operations, 198.
Glass-works, regenerative furnaces for, &c., 318.
Going, T. H., memoir of, 221.
Gordon, G., concrete dam for the Geelong waterworks, 241.
Graham, J., transferred member, 1.
Gramme electro-magnetic machine, experiments with the, 338.
Grant, J., remarks as to Carlingford Lough and Greenore, 143.—Ditto as to the size of the blocks used in the quay wall, 143.
Greenore. *Vide* "Carlingford Lough and Greenore."
Grundy, J., admitted student, 1.
Gruner, L., analysis of the white smoke from a blast furnace, 319.
——, the utilisation of heat in furnaces, 310.
Guibal's fan for ventilating, referred to, 40.

Habets, A., the aërophore Rouquayral-Denayrouze, 325.
Hall, S., his improvements in the marine steam-engine, referred to in the President's address, 7.
Hallauer, O., résumé of Hirn's new work on the mechanical theory of heat, 296.
Handley, H. J., elected associate, 95.
Harbour, "Holyhead New Harbour," 95.—History of the harbour, 96.—Original scheme, 96.—Abandonment of the east breakwater, 97.—North breakwater, 97.—Blasting operations at Holyhead Mountain, 98.—Cost of quarrying the rock, 104.—Staging, 105.—Tipping wagons, 105.—Mode of depositing the stone, 106.—Superstructure of the breakwater, 106.—Cost of the work, 108.—Officials connected with the work, 109.—APPENDIX:—Table I. Area of harbour sheltered by north breakwater, 110.—Table II. Cost of drilling for small shots, 110.—Table III. Abstract from weekly statements of the cost of quarrying and filling 1 ton of stone taken in the year 1855, 111.—Table IV. Progress of breakwater, and the use made of the new harbour by shipping, 111.—Table V. Cost of one bay of the north breakwater staging erected in place in 50-feet

Digitized by Google

depth of water at low water, 112.—Table VI. Prices of the work of the north breakwater, 112.
Harbour, Pola, on the laying of a submarine water pipe, 270.
————, Waterford. *Vide* "Lagoons on the South-east Coast of Ireland."
————, Wexford. *Vide* "Lagoons on the South-east Coast of Ireland."
Harcourt, A. G. V., remarks as to estimating the illuminating power of coal gas, 163.—Ditto as to certain phenomena noted by Mr. Sugg being at variance with common observations, 163.—Ditto as to the description of burner used by Mr. Sugg, 164.
Hardwick, J., elected associate, 95.
Haswell, R. L., on the insufficiency of the tests in use for steel axles, 307.
Hawkshaw, Sir J., remarks as to Holyhead new harbour, 123.—Ditto as to the relative advantages of the rubble mound and the vertical wall for breakwaters, 123.—Ditto as to the alleged attrition of the stones forming the mound at Holyhead, 124.—Ditto as to the causes which led to the adoption of the present design, 124.—Ditto as to a proposed combination of iron and concrete, 124.—Ditto as to the form of the lighthouse, 124.—Ditto as to Carlingford Lough and Greenore, 145.—Ditto as to the deposition of concrete in bags, 145.—Ditto as to some bags of cement which, having been subjected to water, were found to have become solid, and to have assumed the precise shape of the bags, 146.—Ditto as to passing concrete through water, 146.—Ditto as to concrete blocks of 350 tons used at Dublin, 146.—Ditto as to the probable errors of levelling, 199.—Ditto as to cases where great precision in levelling was of the utmost importance, 199.—Ditto as to the influence of good instruments in this respect, 199.—Ditto as to the Royal Saxon Survey, 200.
Haycraft, G., elected associate, 95.
Hayter, H., "Holyhead New Harbour," 95.—Remarks as to blasting the stone for ditto, 113.—Ditto as to the Round Down Cliff, Dover, 113.—Ditto as to the disposition of the débris after exploding a mine at Holyhead, 115.—Ditto as to the alleged silting in the harbour, 125.—Ditto as to the abstract superiority of a vertical wall over a rubble mound failing under conditions like those at Holyhead, 125.—Ditto as to the sum required for maintenance, 126.—Ditto as to the staging, 126.—Ditto as to the form of the breakwater, 126.
Hautefeuille and Troost, MM., on the absorption of gases by iron and steel, 320.
Heat, Hirn's new work on the mechanical theory of, résumé of, 296.
——: on the study of thermic motors, and on certain points of the theory of heat, 292.
——, theory of superfusion and supersaturation, after the principles of the mechanical theory of, 298.
——, utilisation of, in furnaces, 310.
Heberlein break, the, 254.
Helm, O., on the chemical composition of the sewage liquid and effluent water of the Dantzic irrigation works, 276.
Hétet's method of purifying the water from surface-condensers, 284.
Hewitt, G. C., elected associate, 95.
Hildred, J., memoir of, 228.
Hill, R. H., remarks as to the probable errors of levelling, 197.
Hime, Capt. A. H., R.E., elected associate, 1.
Hirn, G. A., on the study of thermic motors, and on certain points of the theory of heat, 292.
——, his method of testing steam-engines, and its application, 293.

Digitized by Google

Hirn, G. A., his new work on the mechanical theory of heat, résumé of, 296.
Hirsch, —, his practice in the general levelling of Switzerland, referred to, 177 *et seq.*
Holyhead harbour. *Vide* Harbour.
Home, W., admitted student, 1.
Hughes' apparatus, automatic, 337.
Hunt, W., transferred member, 95.
Huntington, J. B., remarks as to the ventilation and working of railway tunnels, 79.—Ditto as to the ventilation of long tunnels presenting no insuperable difficulty, 79.—Ditto as to sulphur mines in Italy with galleries 2,000 feet long and 200 feet below the surface, 80.—Ditto as to the traffic through the Channel tunnel being probably small at first, and not requiring elaborate ventilating apparatus, 80.—Ditto as to an arrangement of shafts on each shore for ventilating the Channel tunnel, 81.
Huxley, H. G., elected associate, 95.
Hydraulic experiments at Roorkee, 263.
———— motors of Switzerland, 282.

Innes, E., admitted student, 1.
Ireland, lagoons on the south-east coast of. *Vide* Lagoons.
Iron, on the absorption of gases by, and steel, 320.
——, on the use of cast and wrought, as a material for railway sleepers, 252.
—— bridges, on testing the stability of, 241.
Irrigation works at Dantzic, on the chemical composition of the sewage liquid and effluent water of the, 276.
————, sewage, at Dantzic, the results of, 279.
Isherwood, B. F., on the use of pulverised fuel, 289.

Jacob, A., B.A., transferred member, 1.
——, Capt. S. S., B.S.C., elected associate, 95.
——, T., admitted student, 1.
Johnstone, W., elected associate, 95.
Jones, F. M., admitted student, 1.
——, I. M., elected associate, 95.
——, W. R., elected associate, 95.

Kaiander, N. *Vide* Mendéléeff.
Kick, F., on the relative value of blows and pressure, 302.
Kidd, T., jun., elected associate, 95.
Kinahan, G. H., "The Lagoons on the South-east Coast of Ireland," 204.
Kirsch, L., on the use of cast and wrought iron as a material for railway sleepers, 252.
Kleimvachter, L., regenerative furnaces for glass-works, &c., 318.
Klunzinger, P., narrow-gauge mountain railway from Rostoken to Marksdorf, 247.

Lacroix, E., Hétet's method of purifying the water from surface-condensers, 284.
Lady's Island Lake. *Vide* "Lagoons on the South-east Coast of Ireland."
Lagoons, "The Lagoons on the South-east Coast of Ireland," 204.—Geology of the country between Brattin Head, co. Waterford, and Cahore Point, co. Wexford, 204.—Probable time of formation of the present lagoons, 205.—Origin of

Digitized by Google

the banks inclosing the lagoons, 206.—Wreck of the "Calcutta" in Ballyteige Bay, in 1873–4, 206.—Action of the wind in forming lagoon banks, 206.—Process of silting-up, 207.—The Back Strand at Tramore, 208.—Ballyteige Lough, 209.—Tacumshin and Lady's Island Lakes, 211.—Wexford harbour, 212.—Probability that the banks now dividing Wexford Lagoon from the sea began as shingle beaches on the margin of a flat, 213.—Denudation of Rosslare Bank, 214.—The study of the drift of sand on a sea coast of importance to engineers as well as to geologists, as shown in the case of Wexford harbour, 214.—Connection between the drift of sand and the reclamation of lagoons, 215.—Attempted reclamation of Tacumshin Lake, 216.—Theory that the main drift of sea beaches is due to wind waves contrary to observation and experiment, 216.—Race on the shore of Lyme Bay, 217.—Normal course of the tidal wave in Wexford Bay, 218.

Law, H., remarks as to estimating the illuminating power of coal gas, 164.—Ditto as to all modes of measuring light that ultimately depend upon the human eye being defective, 164.—Ditto as to the employment of Professor Crookes' radiometer as the future standard photometer, 164.—Ditto as to the probable errors of levelling, 196.

Le Breton, A. H., elected associate, 95.

Lefort, —. *Vide* St.-Venant.

Leigh, E., memoir of, 229.

Lemielle's ventilator, referred to, 38.

Lencauchez, A., peat as fuel for industrial and domestic purposes, 289.

Letheby, H., his report on the ventilation of the Metropolitan railway, referred to, 25.—Remarks as to the amount of carbonic acid that may occur in 10,000 volumes of air without injuring health, 57.—Ditto as to the use of lime for purifying the air in tunnels, 59.—Ditto as to estimating the illuminating power of coal gas, 159.—Ditto as to the standard adopted by the Great Central Gas Consumers' Company in 1848, 159.—Early history of gas photometry, 159.—Ditto as to the Sugg-Letheby standard burner for photometrical purposes, 161.—Ditto as to further improvements of Mr. Sugg, 161.—Ditto as to a burner designed for the Birmingham Gas Company, 161.—Ditto as to alternative methods of measuring the intensity of the flame, 162.—Ditto as to Lowe's jet-photometer, 162.—Ditto as to the illuminating power of gas being dependent on the proportions of the rich and heavy hydrocarbons it contained, 162.—Ditto as to the experiments of Dr. Fife and Professor Graham on the flow of gas through a small orifice, 163.—Ditto as to the simplicity of Mr. Sugg's process for testing the illuminating power of gas, 163.

Levelling, "On the Probable Errors of Levelling; with Rules for the Treatment of Accumulated Errors," 174.—Different classes of errors which occur in all levelling operations, 174.—Mistakes, 174.—Instrumental errors, 175.—Errors of observation, 175.—Probable errors of levelling on ground of different degrees of inclination, as deduced from standard levelling in different countries, 176.—Practice of Messrs. Hirsch and Plantamour in the general levelling of Switzerland, 177.—The compilation of tables of probable errors, 178.—Table I. Average differences in a single mile of the results obtained by two observers on ground of different degrees of inclination in Great Britain, India, and Switzerland, 179.—Table II. Average differences in a single mile due to ground of variable inclination, 181.—Table III. Probable errors of the results of single or duplicate levelling on ground of different characters, 182.—Treatment of probable errors in the case of a complex system of levelled lines, 182.—Table IV.

Digitized by Google

Probable errors of lines in a given diagram, 183.—Table V. Final results and effect of the corrections, 183.—Remarks on the instruments and methods of working used in accurate levelling, 185.—Table VI. Instruments and staves used in initial levelling, 185.—Position of benchmarks in England a fruitful source of error, 185.—APPENDIX:—Details of working out an example by the method of least squares, 187.—List of published works on levelling, 192.

Light, electric, for industrial purposes, 339.

Lissauer, Dr., the results of irrigation at Dantzic, 279.

Longridge, J. A., remarks as to the ventilation and working of railway tunnels, 68.—Ditto as to a proposed modification of the horizontal division of a tunnel 68.—Ditto as to the degree of vitiation of the atmosphere which would probably be borne without complaint in a railway tunnel, 69.—Ditto as to the HP. required for ventilating tunnels, 70.—Ditto as to the probable errors of levelling, 194.—Ditto as to the system in vogue for the early railways, 194.—Ditto as to a level furnished with a ball and socket instead of three parallel plates, 195.

Lovell, T., remarks as to the blasting operations at Holyhead Mountain for procuring stone for the breakwater, 115.

Low, W., remarks as to the ventilation of the proposed Channel tunnel, 82.—Ditto as to the preference to be given to a twin tunnel rather than to a single tunnel with two lines of rails, 82.—Ditto as to his report on the "Ventilation of the Channel Tunnel Railway after completion," 83.

Luke, W., transferred member, 1.

Lundie, G. A., elected associate, 95.

M'Connochie, J. A., remarks as to Holyhead new harbour, 127.—Ditto as to the action of the sea on breakwaters with high superstructures and those not above the level of high-water springs being very different, 127.—Ditto as to the probability of high superstructures being abandoned in future breakwaters, 128.—Ditto as to waves of oscillation and waves of translation, 128.—Ditto as to the addition of iron skins to concrete breakwaters being unnecessary, 128.

Manganese, on the effects of silicon and, on the properties of steel, 316.

Marshall, A., B.A., elected associate, 95.

Massauge, —, the Heberlein break, 254.

Mayes, H. P., admitted student, 1.

Mead, A., elected associate, 1.

Mékarski, M., Compressed-air tramway car, 254.

Mendéléeff, D., on the laws of gases, 299.

————, and N. Kaiander, on the co-efficient for expansion of air under atmospheric pressure, 300.

Messent, P. J., remarks as to the use of liquid concrete in bags in the formation of the North Pier at Tynemouth, 149.

Mignon and Rouart, MM., on the artificial cooling of air in considerable quantities by contact with a cooled liquid, 326.

Moncel, Th. du, on the electric conductivity of inferior conductors, 334.

Morant, J. H., elected associate, 1.

Morison, D. P., remarks as to the ventilation and working of railway tunnels, 55.—Ditto as to the means employed for ventilating large coal mines in the North of England, 55.

Morrison, G. J., "The Ventilation and Working of Railway Tunnels," 18.

Motors, hydraulic, of Swizerland, 282.

Digitized by Google

Motors, on the study of thermic, and on certain points of the theory of heat, 292.
Myers, W. B., elected associate, 95.
Mylne, W. C., memoir of, 232.

Napier, F., memoir of, 232.
Nicholson, Surgeon E., experiments on cements at Bangalore, 238.
Noyes, P. A. H., memoir of, 233.
Nubar, B., elected associate, 95.

Oils, lubricating, on, 323.

Pander, J., slipping of the Tiligul embankment on the Odessa-Balta railway, 250.
Parkes, W., remarks as to the Holyhead new harbour, 128.—Ditto as to a comparison of cost between the existing breakwater and one partially composed of concrete blocks, 129.
Parkinson, R. M., admitted student, 1.
Paterson, M. McC., elected associate, 95.
Peat as fuel for industrial and domestic purposes, 289.
Pemberton, Major R. C. B., R.E., elected associate, 95.
————, S. B., admitted student, 1.
Perissé, S., on the temperature of gas furnaces, 312.
Pickwell, R., elected associate, 95.
Pier, Tynemouth, use of bags of liquid concrete in the formation of the, referred to, 149.
Pipes, on the flow of water in, 257.
Plantamour, —, his practice in the general levelling of Switzerland, referred to, 177.
Pole, W., remarks as to the ventilation of the Mont Cenis tunnel, 54.—Ditto as to Carlingford Lough and Greenore, 143.—Ditto as to estimating the illuminating power of coal gas, 166.—Ditto as to the history of the Metropolitan Gas Act of 1868, 166.—Ditto as to the burner chosen by the Gas Referees under that Act, 166.—Ditto as to an equation expressing the light given off by a gas burner, 166.—Ditto as to the difficulty presented to the Gas Referees by the compulsory burning of 5 feet per hour imposed by the Act, 167.—Ditto as to Professor Crookes' radiometer as a means of testing the illuminating power of coal gas, 167.
Poupardin, F. L., Hirn's method of testing steam-engines, and its application, 293.
Pressure, on the relative value of blows and, 302.
Prucha, J., on the closing of an arm of the Danube, 266.
——— on the laying of a submarine water pipe in the harbour of Pola, 270.

Quay walls, use of concrete blocks and bags of concrete in the construction of, referred to, 131 *et seq.*

Radiometer, suggested as a means of testing the illuminating power of gas, 164 *et seq.*
Railway, Breslau-Schweidnitz-Freiburg, in the valley of the Oder, 248.
———, Metropolitan, ventilation of the, 25 *et seq.*
———, Odessa-Balta, slipping of the Tiligul embankment on the, 250.
——— pontoon, steam, 286.
———, Rostoken to Marksdorf, narrow-gauge mountain, 247.
——— sleepers, on the use of cast and wrought iron as a material for, 252.

Digitized by Google

Railway tunnels, the ventilation and working of. *Vide* Tunnels.
Redgrave, G. R., remarks as to Carlingford Lough and Greenore, 144.—Ditto as to whether tidal docks might not have been preferable to a river wall, 145.—Ditto as to the deposition of concrete in bags, 145.
Redman, J. B., remarks as to Holyhead new harbour, 121.—Ditto as to the sites of various national harbours, with reference to the offing and depth of water, 121.—Ditto as to the outline of the pier at Holyhead, 122.—Ditto as to Carlingford Lough and Greenore, 143.—Ditto as to the tides at Carlingford, 144.—Ditto as to the oscillating gangway for foot-passengers, 144.—Ditto as to the fenders, 144.—Ditto as to the probable errors of levelling, 196.
Refrigerating machine, 327.
Reichenbach, O., elected associate, 1.
Richards, H., elected associate, 95.
Rigby, C., remarks as to the powder used for blasting stone for the Holyhead breakwater, 115.—Ditto as to the form in which the headings at the quarries were driven, 116.
——, J., B.A., elected associate, 95.
River Danube, on the closing of an arm of the, 266.
—— Garonne, floods of the, and other rivers in France in 1875, 261.
—— Seine, flood of, in February-March 1876, 262.
Rivers, on the form of the longitudinal and cross sections of gravel-bearing, 258.
Robertson, J., memoir of, 234.
Robinson, R. S., admitted student, 95.
Rouart and Mignon, MM., on the artificial cooling of air in considerable quantities by contact with a cooled liquid, 326.
Round Down Cliff at Dover, method of blasting at the, for the South-Eastern railway, referred to, 113.
Rouquayral-Denayrouze, the aërophore, 325.
Russell, W., elected associate, 95.

Saint-Edme, E., lightning conductors, 337.
St.-Venant, —, on testing the stability of iron bridges. Report on M. Lefort's memoir, 241.
Salmond, T. R., elected member, 95.
Sawyer, E. E., elected associate, 1.
Saxton, H. W., elected associate, 95.
Schantz, H., deep sinking for coal at Peremba in Upper Silesia, 287.
Schwendler, L., on the general theory of duplex telegraphy, 328.
Scriven, W. H., elected associate, 95.
Sewage irrigation at Dantzic, the results of, 279.
——— liquid and effluent water of the Dantzic irrigation works, on the chemical composition of the, 276.
Sharp, J. F., transferred member, 1.
Shoolbred, J. N., remarks as to the probable errrors of levelling, 199.—Ditto as to the Liverpool Ordnance datum, 199.
Siemens, C. W., remarks as to the ventilation and working of railway tunnels, 67. Ditto as to a method of supplying heat to the engine boiler by a clamp of hot bricks in the fire-box, suggested for the Metropolitan railway, and its application to the proposed Channel tunnel, 67.
———, W., measurement of the velocity of transmission of electricity in suspended wires, 332.

Digitized by Google

Silicon and manganese, on the effects of, on the properties of steel, 316.
Silow, P., fluid dielectric constants, 336.
Smith, J. H., elected associate, 1.
Sopwith, T., jun., remarks as to the ventilation and working of railway tunnels, 59.—Ditto as to the variation of atmospheric pressure within and without a tunnel 22 miles long, 60.—Ditto as to the effective HP. that would be required for its ventilation, 61.—Ditto as the limit of vitiation in 10,000 volumes of air, 61. —Ditto as to the amount of carbonic acid generated by a locomotive while in the proposed Channel tunnel, 62.
Spring, W., on the expansion and specific heat of fusible alloys, 320.
Squire, W. W., admitted student, 1.
Steam, on the value of the co-efficient of expansion of superheated, 284.
Steam-engines, Hirn's method of testing steam-engines, and its application, 293.
Steel, on the absorption of gases by iron and, 320.
——, on the effects of silicon and manganese on the properties of, 316.
Steel axles, on the insufficiency of the tests in use for, 307.
Stephenson, G. R., President, address on taking the chair for the first time after his election as President, 1.—Remarks as to the ventilation and working of railway tunnels, 79.—Ditto as to Carlingford Lough and Greenore, 148.
Sternberg, H., researches on the form of the longitudinal and cross sections of gravel-bearing rivers, 258.
Stirling, J., memoir of, 221.
Stoney, B. B., remarks as to Holyhead new harbour, 130.—Ditto as to the attrition of the rubble foreshore, 130.—Ditto as to the cost of the staging, 130.
Story, J. S., elected member, 95.
Street, W. C., elected associate, 95.
Struvé's ventilator, referred to, 37.
Sugg, W., "On Estimating the Illuminating Power of Coal Gas," 151.—Remarks on ditto, 159.—Ditto as to an Illuminating Power Meter, 159.—Ditto as to the variations in the illuminating power of sperm candles, 171.—Ditto as to the Birmingham burner, 171.—Ditto as to his proposition of testing by the height of the flame, 172.—Ditto as to the radiometer, 173.
Surface-condensers, Hétet's method of purifying the water from, 284.
Symons, B., elected associate, 95.

Tacumshin Lake. *Vide* "Lagoons on the South-east Coast of Ireland."
Tamm, A., on the composition of the gases of the Bessemer converter, 313.
Telegraphy, on the general theory of duplex, 328.
Thomson, P., memoir of, 235.
Timber, preservation of, 322.
Tomlinson, J., jun., remarks as to the ventilation and working of railway tunnels, 71.—Ditto ditto as to the Metropolitan railway, 72.—Ditto as to the Mont Cenis tunnel and that proposed under the English Channel, 75.—Ditto as to the futility of comparison between mines and tunnels, 75.—Ditto as to the immunity from sickness of enginemen and firemen employed on the Metropolitan railway, 76.
Tramway car, Mékarski's compressed-air, 254.
Tresca, M., experiments with the Gramme electro-magnetic machine, 338.
Troost and Hautefeuille, MM., on the absorption of gases by iron and steel, 320.
Tscheffkine, General C., memoir of, 219.
Tunnels, "The Ventilation and Working of Railway Tunnels," 18.—Fresh air

Digitized by Google

its composition and properties, 19.—The impurities generated in railway tunnels and their probable amount, 19.—The proportion in which these impurities may be allowed to exist in any space occupied by human beings, 21.—The quantity of fresh air that must be supplied to railway tunnels, according to their length and to the traffic through them, 22.—Analysis of the air in the Metropolitan railway tunnel, October 1867, 26.—Best formula for practical purposes of ventilation, 27.—Experiments in Lime Street tunnel, Liverpool, and at Crewe, 29.—Ventilation of the Mont Cenis tunnel, 32.—Mode in which the length of a tunnel affects the power necessary for ventilation, 34.—Methods hitherto employed for creating a flow of air through underground passages, 37.—Struvé's ventilator, 37.—St. Gothard tunnel ventilator, 38.—Lemielle's ventilator, 38.—Steam-jet ventilator, 38.—Fan used for working the pneumatic tube from Euston to the General Post Office, 39.—The Guibal fan, 40.—Conclusions in respect of tunnels less than 7 miles long, 41.—Application of other than coal-burning locomotives in long tunnels, 42.—Pneumatic system of working tunnels, 43.—Atmospheric system, 44.—Rope system, 46.—Ventilation necessary even where locomotives are not employed, 48.—Conclusions in respect of tunnels more than 7 miles long, 48.

Tyrrell, L. G., admitted student, 1.

Van Sommer, G. A., admitted student, 95.

Vapours, on the mechanical properties of saturated vapours in vacuo, 283.

Ventilation of railway tunnels. *Vide* Tunnel.

Ventilator, Guibal's, referred to, 40.

————, Lemielle's, referred to, 38.

————, Struvé's, referred to, 37.

Viaduct over the valley of the Luech, 246.

Vigers, F., elected associate, 1.

Walker, J. P. H., elected member, 95.

Wastler, J., on the accuracy of chain measurements, 340.

Water, on the flow of, in pipes, 257.

Waterworks, Geelong, concrete dam for the, 241.

Webster, J., elected associate, 95.

Weissenbach, W., the hydraulic motors of Switzerland, 282.

Whewell, Dr., his levelling from Portishead to Axmouth referred to, 193 *et seq.*

Whitmore, J., his report on the ventilation of the Metropolitan railway, referred to, 25.

Wiebe, H., the Breslau-Schweidnitz-Freiburg railway in the valley of the Oder, 218.

Wiedemann, E., on the specific heat of gases, 301.

Wilson, H. B., remarks as to the ventilation and working of railway tunnels, 56.—Ditto as to a proposed underground railway in New York, that was to have been ventilated by a system also suggested for the Metropolitan railway, 56.

Woods, A., remarks as to the probable errors of levelling, 200.—Ditto as to levels taken for the New South Wales Government, 200.

Wrench, J. M., elected associate, 95.

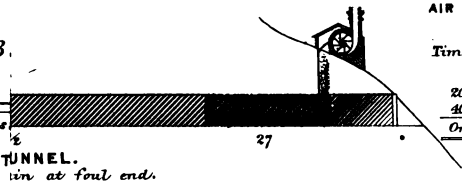
Wyld, R. S., jun., admitted student, 1.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, STAMFORD STREET AND CHARING CROSS.

Digitized by Google

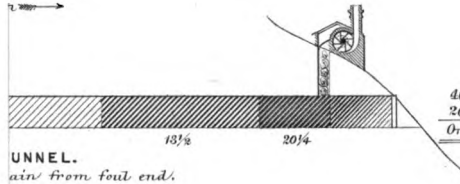
OF T

Fig: 3.



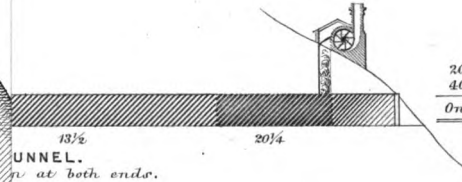
7¼ Miles

OF MONT UNNEL.
in at foul end.

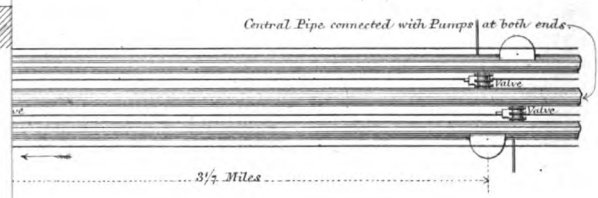


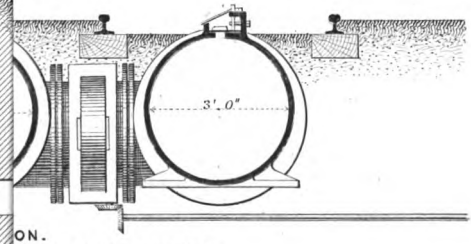
UNNEL.
ain from foul end.

Fig: 4.



UNNEL.
n at both ends.
rections.
rains in one direction only.





ST

SECTION ON.
D TO LONG TUNNELS.

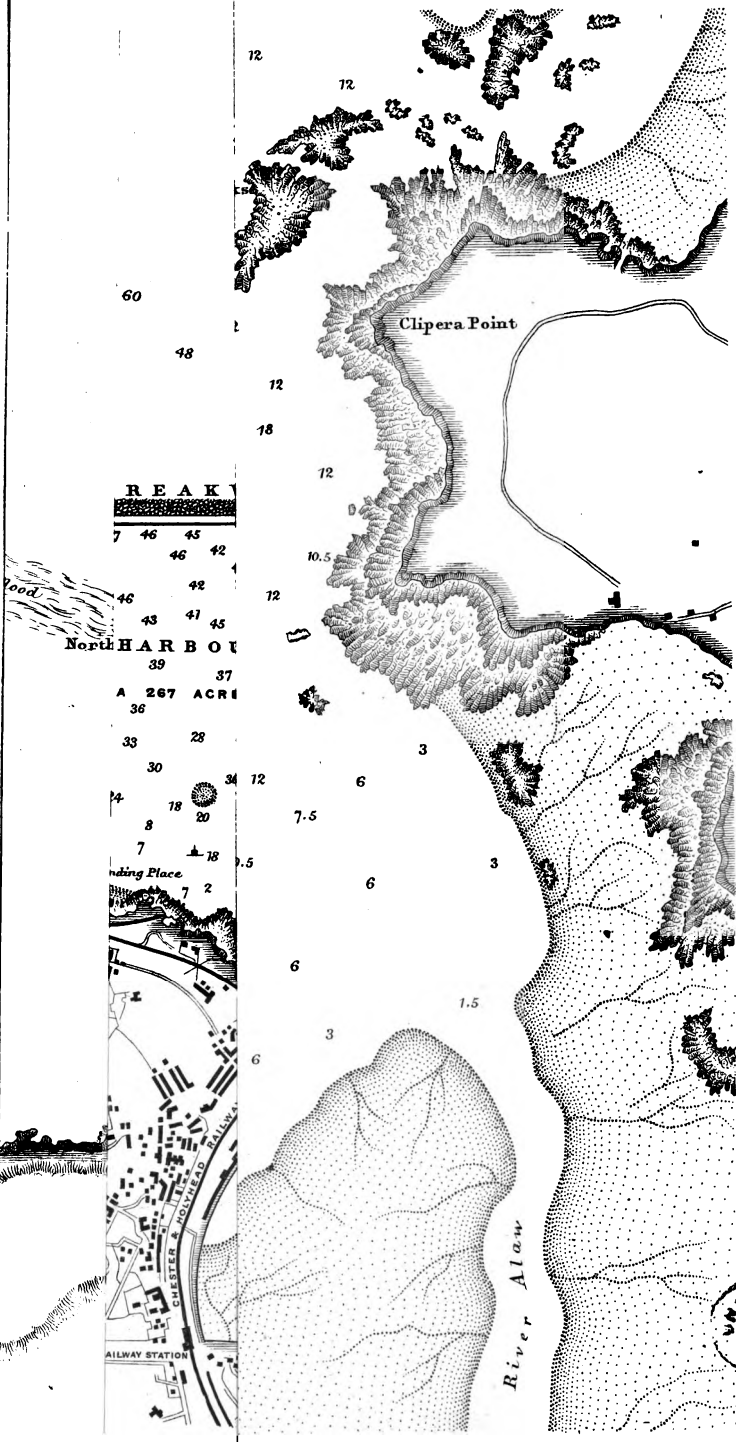
UNIV

neers. Vol:

Digitized by Google

THOS KELL, LITH. 40, KING ST. COVENT

Digitized by Google

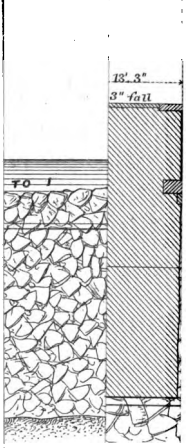


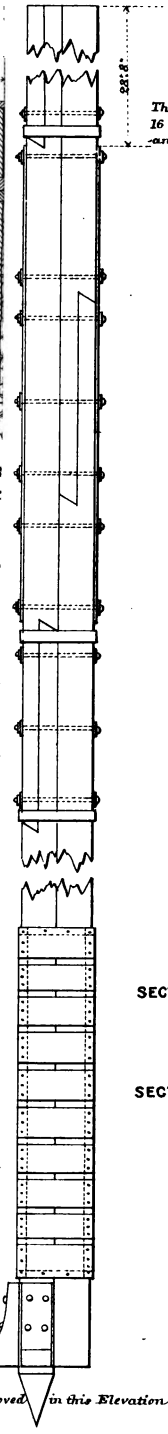
UNIV. OF MICH.

THOS KELL, LITH. 40, KING ST. COVENT GARDEN

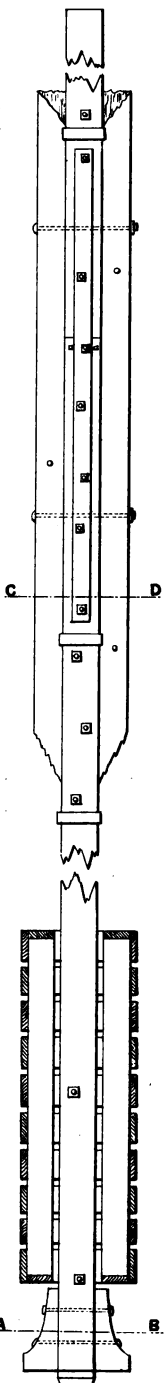
Digitized by Google

Digitized by Google



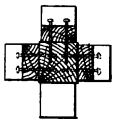


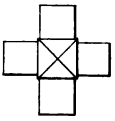
The Fish pieces are put about 16 feet from the top of the Pile and are 40 feet in length.



SECTION THROUGH C.D.

SECTION THROUGH A.B.



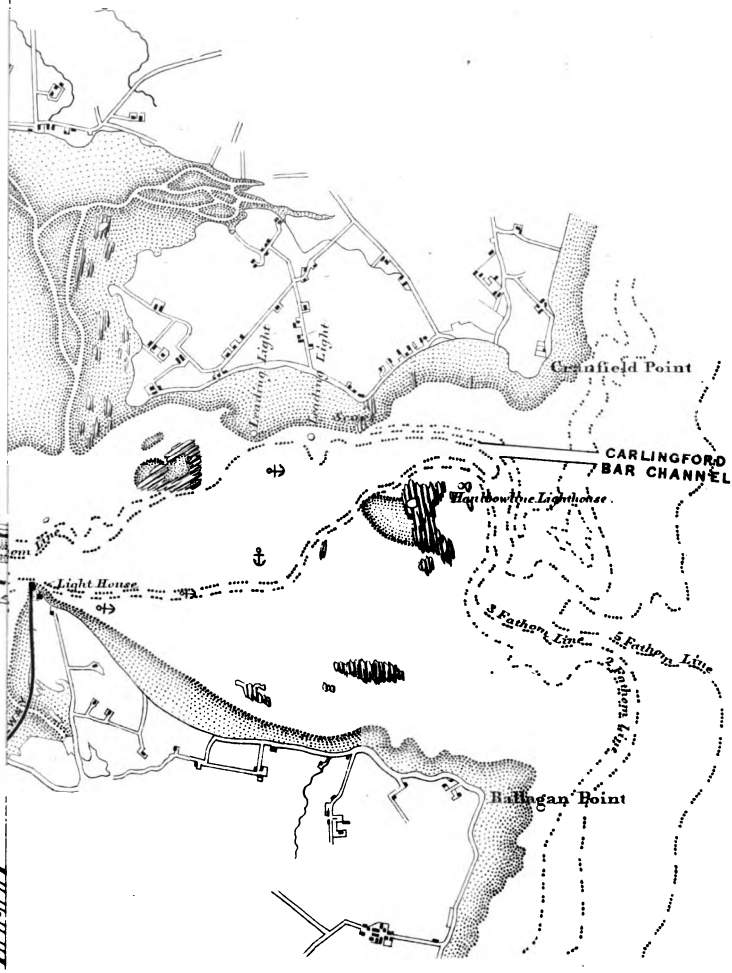


PLAN OF FOOT.

THOS KELL, LITH 40, KING ST COVENT GARDEN

Digitized by Google

Digitized by Google



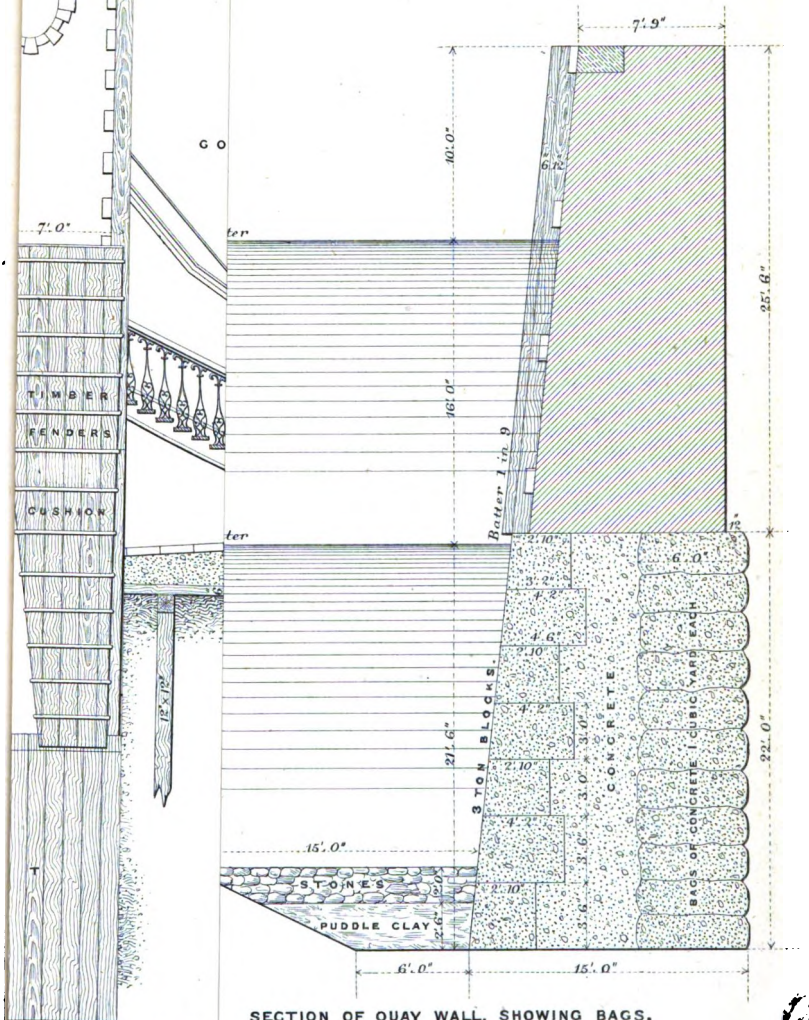
CHANNEL.

20 Feet — 1 Inch.

THOS KELL, LITH. 40, KING ST. COVENT GARDEN

Digitized by Google

Digitized by Google



SECTION OF QUAY WALL, SHOWING BAGS.

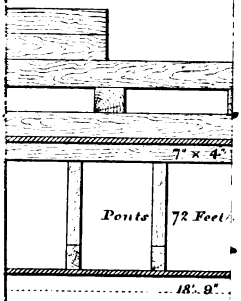
THOS KELL, LITH. 40, KING ST. COVENT GARDEN

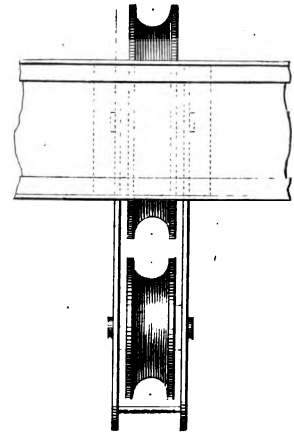
Digitized by Google

Digitized by Google

CARLINGF

APPARA

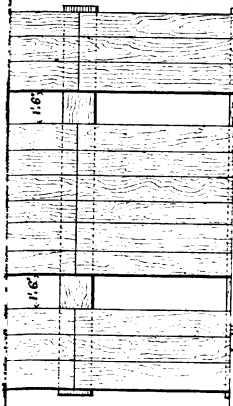




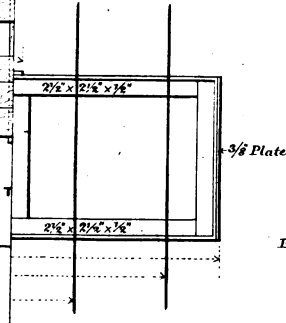
PONT

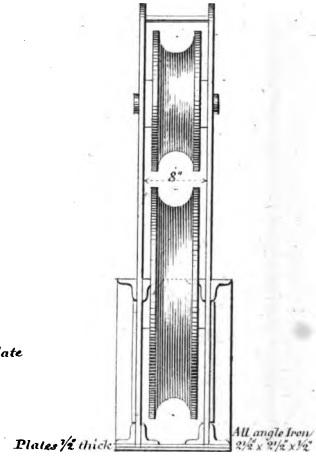
UPPER SHEAVES.

21'. 0"



PONT





LOWER SHEAVES.

Scale for Enlargements: 2 Feet — 1 Inch.

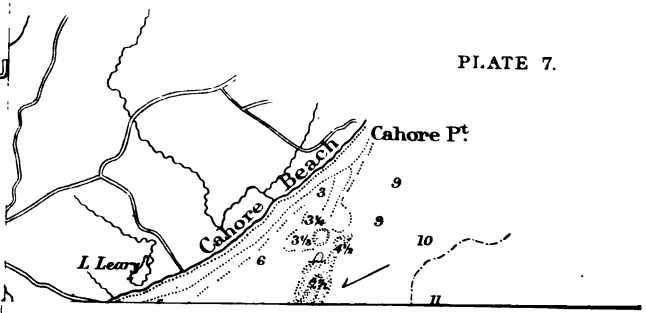
THOS KELL, LITH 40, KING ST COVENT GARDEN

Digitized by Google

Digitized by Google

IS ON THE SOU

ILED FROM STAFF



Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google